Survival and Cause-Specific Mortality of White-tailed Deer in Southeastern Kentucky

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Abstract: White-tailed deer (*Odocoileus virginanus*) are the most sought after game species in Kentucky. Deer numbers in southeast Kentucky are relatively low compared to other areas of the state, even after a decade of restrictive doe harvest and prior population supplementation. We estimated survival and assessed cause-specific mortality of a representative deer population in this low-density area within or near the Redbird District of the Daniel Boone National Forest in southeastern Kentucky from January 2014–January 2017. Estimated annual survival for does averaged 0.89 and was relatively high compared to similar studies. Deer-vehicle collisions and poaching caused 13 of 18 (72%) deaths. We recommend longer-term studies at these and other sites in this area to better understand deer population dynamics and their relationship to important habitat components so as to inform regional management of this important game species.

Key words: Appalachia, Kentucky, *Odocoileus virginianus*, management, population, survival, white-tailed deer

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White-tailed deer (*Odocoileus virginianus*; hereafter, deer) population growth and range recolonization in the United States during the past century is one the most important examples of successful wildlife management. Reintroduction programs, population supplementation, and restrictive harvest policies have resulted in a North American deer population that is thought to exceed that which existed just prior to European settlement (Heffelfinger 2010). Abundant deer populations in many areas, and the popularity of deer hunting, have resulted in deer being the most frequently harvested big-game species in the United States; consequently, deer hunting is a positive contributor to local economies (Grado et al. 2007, Conover 2011). Deer in some areas of the United States are now considered overabundant and ecologically destructive, and higher numbers have resulted in frequent human-wildlife conflict (Waller and Alverson 1997, Stewart et al. 2007). Even so, while many regions of the United States have experienced high deer numbers, some regions, including portions of the central Appalachians and other areas of the southeastern United States (Giuliano et al. 2009), have failed for decades to meet deer population goals.

Kentucky is an excellent example of the wide regional disparity in deer numbers experienced by many states. Approximately 2000 deer remained in Kentucky in the early 20th century before extensive restocking and enforcement facilitated population growth (Gassett 2001) resulted in a statewide estimate of approximately 1 million deer in 2012. Deer population growth during this period was most rapid in the western two-thirds of the state, while that in southeastern Kentucky remained unsatisfactory despite hundreds of thousands of dollars spent on restocking efforts that lasted through 1998 (Gassett 2001).

Predation (DeYoung 1989, Kilgo et al. 2010), disease (Davidson and Doster 1997), poor habitat (Teer et al. 1965), winter severity (Bowyer et al. 1986), poaching (Smith 1966), and legal harvest (Campbell et al. 2005) are important factors that affect the survival of white-tailed deer; however, only two field studies of deer mortality were conducted prior to 2000 in eastern Kentucky (Pais 1987, Cox 2003). Pais (1987) found feral dogs (*Canis lupus familiaris*) to be an important cause of deer mortality in southeastern Kentucky, while Cox (2003) found hunting, poaching, and road collision to be the primary causes of deer mortality in the same region. In addition, deer hunters in southeastern Kentucky frequently blamed

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the recent arrival of coyotes (*Canis latrans*) for stagnant deer numbers (C. Haymes and J. Cox, personal observations). Recent studies in the southeastern United States have also implicated the coyote as an important source of deer neonate (*sensu* Kilgo et al. 2012, McCoy et al. 2013, Nelson et al. 2014) and adult (Chitwood et al. 2015) mortality. Cox (2003) commonly found deer in coyote scats at two different study sites within southeastern Kentucky, but did not find coyote predation to be a cause of mortality for a small ($n=24$) sample size of radio-collared adult deer simultaneously monitored at one of these sites.

Previous studies of adult deer in southeastern Kentucky provided little information as to why regional numbers appeared to remain low. Therefore, we used radio-telemetry to investigate mortality-related factors that could be responsible for suppressing regional population growth in this landscape comprised primarily of a mosaic of mixed-mesophytic forest and limited agriculture. Our objective was to estimate annual survival and to determine cause-specific mortality of white-tailed deer from 2014–2017. We hypothesized that poaching and road collision would be primary sources of mortality in this region and that annual survival estimates would also be low (<50%) given the perception of very low regional deer numbers by local hunters and wildlife biologists.

Methods

Study Area

Our study was conducted in Clay and Leslie Counties, Kentucky, located in the Cumberland Plateau physiographic region of Kentucky (Figure 1). Clay County was 758 km^2 and Leslie County 650 km^2, both being characterized by relatively steep mountains typical of the Central Appalachian mountain range. Elevation ranged from 366–671 m, and ridges were frequently dissected by deep dendritic drainages (Moore and Dotson 2003) leading to small river and creek bottoms. Flatter slopes were present along the rivers and creek drainages; roads, farms, and agricultural fields or small grasslands often occur in these floodplains. Average annual rainfall in this region was ~130 cm (51 in), and average temperatures ranged from –5.5 to 28.9 ºC (USCD 2016).

Research was conducted at two sites with very similar land cover types, Oneida and Redbird, in Clay and Leslie Counties, Kentucky. The Oneida site was comprised mostly of private land (67.9%) with smaller blocks of the Daniel Boone National Forest scattered around the township of Oneida. The township was located at the confluence of the Redbird River and Goose Creek, which form the headwaters of the South Fork of the Kentucky River. The Redbird site was 66.8% publicly owned and was managed by the U.S. Forest Service (USFS) as part of the Daniel Boone National Forest, with Kentucky Department of Fish and Wildlife Resources jointly operating Redbird Wildlife Management Area (WMA) with USFS. All portions of both study sites were open to public hunting under statewide regulations as Zone 4 counties, which allows taking of either sex of deer except during modern gun season and other limited periods.

We used the Raster Clip tool in ArcGIS version 10.2 (ESRI, Redlands, California) to clip the 2011 National Land Cover Dataset (Homer et al. 2015) with a 203.3-km^2 circle (8-km radius) that encompassed our deer trap locations to determine general land cover types of the two sites. Oneida was comprised of 84.6% mixed-mesophytic forest, 9% pasture, 5.3% human settlement, 1% open water, and 0.1% crops. Redbird was comprised of 87.4% mixed-mesophytic forest, 7.4% pasture, 4.7% human settlement, and 0.5% open water. Oak-hickory-beech (*Quercus-Carya-Fagus*) forests dominated the study areas. Other co-dominant trees species included red maple (*Acer rubrum*), sweet gum (*Liquidambar styraciflua*), and yellow poplar (*Liriodendron tulipifera*). Pastures were comprised of tall fescue (*Schedonorus arundinaceus*) and various clovers (*Trifolium spp.*). Soybeans (*Glycine max*) and corn (*Zea mays*) were the most common commercial crops.

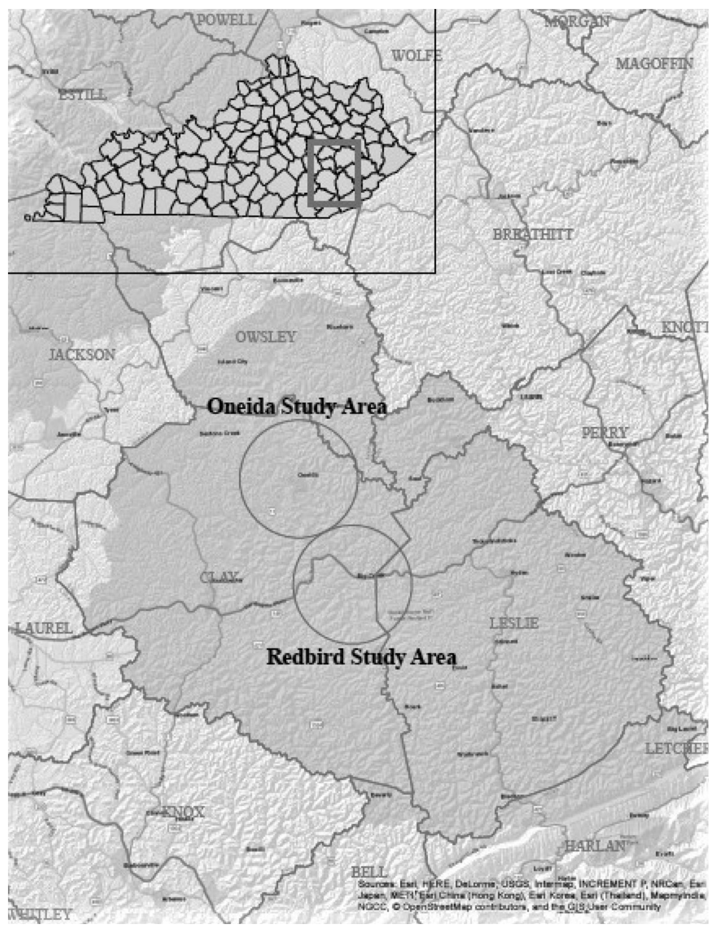

Figure 1. Study Areas in Clay and Leslie Counties, KY.

We captured deer using a 18.3- x 18.3-m drop net, 17.4- x 13.1-m rocket nets, and 1.83- m long x 0.91-m wide x 1.22-m tall Clover traps (Clover 1956), all baited with shelled corn. Clover traps were deployed in forests and in grassy clearings where space was insufficient to deploy drop-nets. We checked clover traps every 12 hours. Rocket net setups included four Winn Star Type 15 rockets (Winn Star Inc., Carbondale, Illinois) wired in sequence to a Handi-Blaster firing mechanism (Blasters Tool and Supply Co., Inc., Lawrenceburg, Kentucky) with 20-gauge lamp cord. We monitored deer activity at drop and rocket net sites from vehicles using a forward looking infrared scope (Scout II 320, FLIR Systems, Inc.), and by using a single trail camera (Bushnell Trophy Cam 8MP) mounted to a drop net pole.

We physically immobilized and blindfolded deer, then intramuscularly injected them in the shoulder or hip with 1–1.5 mL of BAM (Butorphanol Tartrate 27.3 mg/mL – Azaperone Tartrate 9.1 mg/mL – Medetomidine HCl 10.9 mg/mL) (Zoophar, Inc., Laramie, Wyoming) (Mich et al. 2008) per ZooPharm guidelines according to general age class (juvenile (<1 y.o.) or adult (>1 y.o.). We recorded heart rate and dissolved oxygen levels using a Masimo Radical 5 pulse oximeter (Masimo Corporation, Irvine, California), and recorded breathing rate and temperature using visual cues and a rectal thermometer, respectively; these physiological parameters were collected at ~5-minute intervals. Juvenile and adult does were fitted with a Lotek LMRT-2 (Lotek Inc, Newmarket, Ontario, Canada) very high frequency (vhf) radio collar equipped with a mortality sensor that changed pulse rate when the collar remained motionless for >4 hours. We fitted each deer with a uniquely numbered 2.5-cm plastic stud ear-tag (National Band and Tag, Newport, Kentucky) inscribed with study personnel contact information to facilitate communication when a deer was harvested or found dead. We administered a submucosal dental nerve block of 2% Lidocaine solution (Hospira Inc., Lake Forest, Illinois) in the mandible gumline, and then pulled the fourth incisor for cementum annuli age analysis (Gilbert 1966). We also recorded standard body measurements including weight, total body length, chest girth, hind-leg length, and front shoulder length (Bender et al. 2007). Does estimated to be ≥1.5 years of age or older were fitted with a vaginal implant transmitter (Bishop et al. 2011; Advanced Telemetry Systems, Isanti, Minnesota) to facilitate the capture of fawns for a companion study. We antagonized BAM-drugged deer using 2–3 mL (according to dose) of Atipamezole (25 mg/mL) and 0.5–1 mL of Naltrexone HCl (50 mg/mL) (Zoophar, Inc., Laramie, Wyoming), then observed the study animal from ~25 m away until they successfully regained safe mobility. All capture and handling procedures were approved by the University of Kentucky IACUC #2013-1138.

We monitored radio-collared deer via triangulation and homing using ground telemetry or aerial telemetry from a fixed-wing aircraft. Deer were located daily using ground telemetry during the first four weeks post-capture to detect potential capture myopathy deaths, and weekly thereafter. We classified mortalities as roadkill if deer were discovered ≤20 m of a roadway, if we found broken vehicle parts near deer carcasses, and/or when impact trauma (e.g., road rash, bruising, and hair on the roadway) was evident. We classified a deer as illegally harvested when radio-collars were found cut off of the deer and predation signs or hunter-killed gut piles were absent, or when deer were otherwise harvested outside of legal harvest seasons. The presence of all-terrain vehicle tracks and/or a hidden collar (one that appeared to be a deliberate human act of concealment), were also considered supporting evidence of illegal harvest. A deer was classified as harvested/hunted when it was reported or communicated with us directly. Death from illness was determined from lab results after submission to the Southeastern Cooperative Wildlife Disease Study. A predation event was determined by the presence of subcutaneous bruising typical of bite pressure from a predatory attack. Illness and predation were pooled for analysis due to the low sample size of each mortality cause and together were considered "natural causes."

We determined survival estimates using the Kaplan-Meier estimator modified for staggered entry (Pollock et al. 1989). A Mantel-Haenszel log-rank test was performed to determine statistical differences between years, ages (juvenile vs adult), and study areas (Mantel and Haenszel 1959). We also estimated cause-specific mortality rates using Cox proportional-hazards regression modelling (Cox 1972), and calculated survival and mortality using RStudio Version 1.0.136 with the Survival Package (Therneau 2015). Deer were right censored from the survival analysis if they were believed to have succumbed to capture myopathy, radio contact was lost, or the collar slipped off. We considered deer that died within four weeks of capture to have succumbed to capture myopathy, and these individuals were removed from the survival analysis (Haulton et al. 2001). Does which were <1 year old at the time of capture were included in the study because they are part of the huntable population, and thus subject to the same mortality pressures as adults.

Results

We captured 97 (2014 = 5 JF, 21 AF; 2015 = 14 JF, 22 AF; 2016 = 13 JF, 22 AF) individual does from 2014–2016; 95 were collared and monitored for 50,471 radio-days with an average of 531 radio-days per doe. One adult and one juvenile doe died during the capture process and were never fitted with collars (2.1%), and two (2.1%) adult does died from capture myopathy within 12 days post-capture, resulting in 93 does included in the survival analysis. Five (5.3%) juvenile does slipped their collars or lost collar signal and were subsequently right censored at those time periods. We found no significant differences in estimated annual survival between years ($P=0.55$), age classes ($P=0.80$) or study areas ($P=0.97$); therefore, we report annual survival estimates and mortalities pooled from adults and juveniles. Estimated doe survival was 0.89 (95% CI = 0.55–0.94) in 2014, 0.86 (95% CI = 0.78–0.96) in 2015, and 0.91 (95% CI = 0.85–0.98) in 2016.

Eighteen (18.6%) does died during the study. Vehicle collisions caused 8 of 18 (44.4%) deaths (2014 = 2, 2015 = 4, 2016 = 2) for a mortality rate of 0.22, SE = 0.08. Illegal harvest accounted for five deaths (27.7%, 2015 = 1, 2016 = 4; mortality rate = 0.07, SE = 0.03), while legal harvest accounted for three of 18 (16.7%, 2015 = 2, 2016 = 1) deaths for a mortality rate of 0.05, SE = 0.03. Two does (11.1%, 2016 = 2) died from natural causes (cancer = 1 and predation = 1) with a mortality rate of 0.03, SE = 0.02.

Table 1. Estimated survival and cause-specific mortality rates of select studies of adult white-tailed deer in the eastern United States.

Study	State	Survival rate	Sex	Hunting	Mortality Rate		
					Poaching	Roadkill	Natural[a]
This study	KY	0.89	Female	0.05	0.07	0.22	0.03
Cox 2003	KY	0.87	Both	0.09	0.09		
Storm et al. 2007	IL	0.87	Female	0.09	0.02	0.02	
Etter et al. 2002	IL	0.83	Female	0.02	0.03	0.06	
Patterson et al. 2002	NS[b]	0.80	Female	0.02	0.06	0.02	
VanDeelen et al. 1997	MI	0.77	Female	0.04		0.08	
Brinkman et al. 2004	MN	0.75	Female	0.08		0.05	0.01
Kunkel and Pletscher 1999	MT	0.74	Female				0.23
Fuller 1990	MN	0.69	Female	0.15	0.05	0.06	
DePerno et al. 2000	SD	0.57	Female	0.04			0.12

a. Includes predation and illness
b. Nova Scotia, Canada

Discussion

Climate change (Unsworth et al. 1999, Samuel 2007), disease transmission (McNay and Voller 1995, Bleich et al. 2015), and predation (Keller et al. 2015) have been implicated as causes of population decline in several species of North American ungulates. Although predation (Patterson et al. 2002), disease (Nettles and Stallknecht 1992), and deer vehicle collisions (Etter et al. 2002) can be major contributors to deer mortality in some areas, hunting is by far the largest source of deer mortality in most areas of the United States (Nelson and Mech 1986, Dusek et al. 1992, Van Deelen et al. 1997).

Given the low deer numbers that have plagued this region for decades, we surprisingly found doe survival in southeastern Kentucky to be much higher than predicted, even exceeding comparable studies (Table 1; Dusek et al. 1992, McCorquodale 1999, DePerno et al. 2000, Etter et al. 2002, Patterson et al. 2002, Robinson et al. 2002). Only three study animals were legally harvested (all with archery) during the three-year study period, and the resultant hunter harvest mortality rate (0.05, SE = 0.03) was similar to other studies where doe harvest is allowed (Table 1; Van Deelen et al. 1997, DePerno et al. 2000, Patterson et al. 2002, Campbell et al. 2005). High survival rates of white-tailed deer females in a hunted population may be a function of restrictive doe-hunting regulations (Van Deelen et al. 1997), which were the case in our study area. Jacques et al. (2011) also found that radio-collars may influence a hunter's decision to legally harvest an animal. We undertook public education measures to inform hunters in the study area that radio-collared deer were legal quarry, but we were unable to identify any potential bias against harvesting our study animals that may have affected survival rates.

Poaching can undermine deer management goals. McCorquodale (1999) observed illegal harvest to be the leading cause of female mortality of black-tailed deer in Washington. We estimated illegal harvest (0.07, SE = 0.03) in our study to be slightly higher than others (0.02– 0.06; Table 1; Nelson and Mech 1986, Nixon et al. 1991, Etter et al. 2002, Patterson et al. 2002, Fuller et al. 2007, Storm et al. 2007). Illegal harvest was identified as the cause of death of five radio-collared deer in our study; three of the cases involved does killed during a buck-only hunting season, and two other deer were killed outside of any deer hunting season. Muth and Bowe (1998) suggested most poaching events occur during the hunting season under the guise of legal harvest. Studies of poaching in the United States reported low (1:83–1:30) ratios of reported incidences to actual incidences, suggesting that the amount of poaching that managers know of through law enforcement is only a small portion of the actual amount of poaching (Eliason 2003, Green et al. 1988, Kaminsky 1974, Vilkitis 1968).

We found vehicle collisions were a major cause of deer mortality in our relatively low road density rural study area, and were higher (0.22, SE = 0.08) than other studies (Table 1; Etter et al. 2002, Robinson et al. 2002). It should be noted, however, that due to capture method constraints and trapping success, deer in our study were primarily captured in or near river bottoms where roads cooccurred (Finder et al. 1999), which could have inflated the relative importance of vehicle collisions as a source of regional deer mortality. Convenience sampling plagues many wildlife studies and thus caution should be exercised when statistics are extrapolated to the broader population (Nusser et al. 2008). Nonetheless, Ng et al. (2008) reported a positive association between deer-vehicle collisions, riparian areas, and non-forested agricultural areas. Curved roads were common in our study and can lead to increased deer-vehicle collisions (Grilo et al. 2011).

Deer are susceptible to a myriad of diseases (Davidson 2006), but we observed only one disease-related (cancer) death from disease. Typically, the most influential disease that affects deer populations in Kentucky is epizootic hemorrhagic disease (EHD) (Nettles and Stallknecht 1992). Past EHD outbreaks have been observed in our study area, but the disease was not observed during our study (Jenkins and Brunjes 2013). However, a major regional outbreak of EHD subsequently occurred throughout much of eastern Kentucky just after our study ended.

Predation can strongly influence deer population dynamics in areas with large carnivores (Nelson and Mech 1986, Fuller 1990, DelGiudice et al. 2002). Predation on adult deer in the southeastern United States was likely drastically different 250 years ago when wolves (*Canis lupus*, *Canis rufus*) and cougars (*Puma concolor*) co-occurred with deer and other sympatric ungulates. In the absence of wolves and cougars, coyote, black bear (*Ursus americanus*), bobcat (*Felis rufus*), and feral dog have become the primary predators of deer. In North Carolina, Chitwood et al. (2015) reported four confirmed predation events on healthy, adult female white-tailed deer by coyotes. Other studies suggest that the recent invasion of the western coyote into the east may significantly impact deer populations in the southeastern United States (Kilgo et al. 2010). We observed one predated adult doe (predator species undetermined). This individual experienced a difficult capture with a prolonged induction period and survived past the one month capture myopathy window, but remained within 200 m of the trapping location until a mortality signal was detected. It is possible that a weakened condition brought about by capture stress facilitated predation.

Management Implications

Single-species wildlife management ideally relies on use of the best available data to inform decisions. Managers often require data collected at smaller spatial scales to inform county or region-level management, particularly in areas where traditional harvest-focused management regimes fail to produce desired population outcomes. This study was conducted over a relatively short period (three years), but identified factors that are likely influencing population dynamics in a region of relatively low deer density. We found humans (vehicle collisions and harvest; both legal and illegal) to be the two primary causes of adult deer mortality in southeastern Kentucky. Given the relatively high annual estimated survival (0.89), our findings suggested that factors other than adult survival, such as fawn survival or habitat quality and availability, may play a relatively more important role in regional deer population dynamics. Giuliano et al. (2009) categorized Central Appalachia as "good quality" habitat for white-tailed deer, but the high adult deer survival we and others (Cox 2003) have found warrants investigation into other factors, including those that are habitat-related, that may play a relatively more important role in deer population dynamics. We therefore highly recommend that long-term monitoring of population metrics (survival, natality) be accompanied by resource selection studies to better understand factors responsible for the relatively low deer densities that have long plagued wildlife managers and frustrated hunters in this region.

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