Human Dimensions Article

Survival of Neonatal White-Tailed Deer in an Exurban Population

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ABSTRACT As humans continue to move further from the urban epicenter and expand into suburban and exurban areas, problems involving coexistence of wildlife and human populations will become increasingly common. Wildlife biologists will be tasked with reducing wildlife–human conflicts, and their effectiveness will be a function of their understanding of the biology and life-history characteristics of wildlife populations residing in areas with high human density. In this study, we examined causes and timing of deaths of neonatal white-tailed deer (*Odocoileus virginianus*) in an exurban area of Alabama in 2004 and 2005, estimated survival rates, and determined factors that influenced survival for the initial 8 weeks of life. We found 67% mortality, with the leading causes being predation by coyotes (*Canis latrans*; 41.7%) and starvation due to abandonment (25%). These results suggest that coyote predation may be a significant source of natural mortality in exurban areas. Contrary to our original expectations, vehicle collisions were not an important cause of mortality. (JOURNAL OF WILDLIFE MANAGEMENT 71(3):940–944; 2007)

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As humans continue to move further from the urban epicenter, wildlife–human conflicts have been increasing. Once a suitable habitat for only a few species, human settlements are now designed in such a way that allows wildlife to live alongside human populations (Ditchkoff et al. 2006). This new landscape (deemed exurbia) is characterized by a mixture of suburban and rural qualities including a combination of farms, forests, estates, and large-acreage suburbs (Nelson 1992). By creating larger lots and maintaining native vegetation between houses, wildlife populations can better co-exist with urban expansion. Beginning in the 1990s, exurbia has been developing faster than all other landscape types (Nelson and Sanchez 2005). Because of this, management of wildlife populations residing in these areas is becoming increasingly important (Ditchkoff et al. 2006). White-tailed deer (*Odocoileus virginianus*) have caused considerable concern in these areas due to overabundant populations and increased wildlife–human conflicts (e.g., vehicular accidents and foraging on landscaping).

A large amount of natural mortality in white-tailed deer occurs during the first few months of life. Although numerous studies on survival of neonatal white-tailed deer have been conducted (see Linnell et al. 1995), none have focused on exurban or suburban populations. Wildlife residing in exurban or suburban areas are exposed to different predation and mortality risks such as vehicular traffic (Forman and Alexander 1998, Koenig et al. 2002) and predation by domestic animals (Koenig et al. 2002, Gillies and Clout 2003, Lepczyk et al. 2003). These different sources of mortality have the potential to alter survival and population growth, which then influences management decisions. In Missouri, USA, adult mortality was similar between urban and rural (forested and agricultural) areas; however, causes of mortality were different with vehicular accidents replacing hunting mortality in urban areas (Hansen and Beringer 2003). Additionally, deer–vehicular collisions were the greatest cause of adult white-tailed deer mortality in Chicago, Illinois, USA (Etter et al. 2002). Despite the impacts such differences in mortality risks can have on management, management decisions for exurban and suburban areas have been based on knowledge obtained from rural areas. Thus, we examined cause and timing of death of neonatal white-tailed deer, estimated survival, and evaluated potential factors that influenced neonate survival in an exurban area in Alabama, USA.

STUDY AREA

Our study site was located in an exurban area of Auburn, Alabama. Our study area consisted of a cluster of large-acreage suburban developments with 0.4–2.0-ha lots, which maintained much of the native vegetation and wooded areas between houses, suitable for wildlife corridors. In addition, we examined deer from Chewacla State Park, Auburn, Alabama, a 281.3-ha tract of land, surrounded by these suburban developments. Our study area was divided by low-density 2-lane suburban streets and bordered by a major interstate (I-85) with high-speed traffic. Deer on this site regularly crossed roads and lived in close proximity to human populations.

METHODS

Between March and August in 2004 and 2005, we captured and fitted adult female white-tailed deer ($n = 46$) with vaginal implant transmitters (Models M3950 and M3930; Advanced Telemetry Systems, Isanti, MN). We anesthetized captured deer similar to Kilpatrick and Spohr (1999) using an intramuscular injection of telazol (250 mg) and xylazine (200 mg), administered with dart guns over areas

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baited with whole corn. We inserted a vaginal implant transmitter approximately 15–20 cm into the vaginal canal of each anesthetized deer, with the silicone wings pressed firmly against the cervix (Carstensen et al. 2003). These transmitters were specifically designed to be expelled during the birth process and emit a signal when the temperature of the transmitter changed from 34° C to 30° C (Bowman and Jacobson 1998). In addition, while females were anesthetized, we removed the first incisor similar to Nelson (2001) and we determined age of the female from annuli in the cementum (Matson's Laboratory, Milltown, MT; Low and Cowan 1963, Gilbert 1966). We reversed all females with an intramuscular injection of tolazoline hydrochloride (200 mg).

We monitored females approximately every 8 hours beginning in July through August to locate neonates soon after birth. Once a transmitter was expelled, we waited $\geq$4 hours after the pulse rate switched to locate the birth site through hand-held telemetry. We applied these methods to ensure adequate time for mother–neonate bonding and to maintain some consistency in the amount of time following birth that we caught and weighed neonates. If the neonate had moved from the birth site, we expanded the search area to a 200–300-m radius around the birth site as described by Carstensen et al. (2003). In addition, we used a thermal-imaging camera (Thermal-Eye 250D; L-3 Communications Infrared Products, Dallas, TX) to help locate neonates moved from the birth site. Once located, we captured each neonate by hand with the use of nonscented latex gloves. We weighed and radiotagged each neonate using an expandable radiocollar (Model M4210, Advanced Telemetry Systems; Diefenbach et al. 2003), allowing us to monitor survival for approximately 6–12 months. These collars were designed to give a signal if activity was undetected for 6 hours and included a coding system allowing us to determine the exact time motion ceased. We restricted handling to $<$10 minutes and 1–2 handlers. The Institutional Animal Care and Use Committee (Auburn University, AL; No. 2003–0530) approved all handling procedures.

Following release, we located each neonate more than once per day. We ascertained cause of death for each mortality. We distinguished predators by comparison of location and description of remains, hair found at site, and bite marks (Cook et al. 1971, White 1973, Garner et al. 1976). When we could not determine conclusively that predation was the cause of death, but evidence suggested predation (e.g., found only collar with bite marks or near predator scat or time exceeded 24 hr following death and scavenging could not be eliminated as a possibility), we classified the neonates as possibly predated. We necropsied those neonates for which causes of death could not be determined in the field. We identified emaciation similar to Sams et al. (1996) by severe atrophy of adipose tissue, absence of gastrointestinal contents, and presence of meconium in lower intestines. However, we were normally unable to determine the cause of emaciation. Potential causes included natural abandonment, human-induced abandonment, mortality of mother, mother unable to return to neonate, and neonate being unable to nurse. If we were unable to determine cause of death by these procedures we classified it as unknown.

We performed survival analysis with a known-fate model in program MARK version 4.2 (White and Burnham 1999). We modeled weekly survival for the initial 8 weeks of life (56 d), the approximate time before weaning occurred. We developed a candidate model set consisting of 18 models including time following birth (i.e., survival was different among the 8 weeks following birth), a linear time trend (i.e., survival for each week following week was related in a linear trend over time), and individual covariates: year (coded: $2004 = 1$; $2005 = 0$), mass of neonate at birth, sex of neonate (coded: $M = 1$; $F = 0$), birth date, and age of mother (divided into 2 groups; coded: $\leq 2.5 = 0$ and $>2.5 = 1$). We used Akaike's Information Criterion corrected for small size (AIC_c) to select the best models and calculated parameter likelihoods, estimates, standard errors, and odds ratios from the estimates given by MARK. To test the goodness-of-fit of the most general model, we used Hosmer and Lemeshow goodness-of-fit statistic (PROC LOGISTIC; SAS Institute, Cary, NC). In addition, we used a *t*-test to test for differences in birth date and birth mass between years. We used a chi-square to test for differences in survival between years. We also tested for differences in mother's condition (i.e., age and chest girth) among neonates that lived, died due to emaciation, and died of all other causes with an analysis of variance.

RESULTS

We implanted 46 females in 2004 and 2005 with vaginal implant transmitters, of which 28 resulted in the successful captures of neonates (8 sets of twins, 20 singletons). Unsuccessful captures from transmitters resulted from premature expulsion of transmitter ($n = 9$), transmitter failure ($n = 2$; one of which we replaced), transmitter malfunction (i.e., irregular pulse rate; $n = 1$), failure to locate neonates after birth ($n = 1$), and implantation of infertile or postparturition females as determined by expulsion of transmitter after birthing season ($n = 6$).

We captured a total of 36 neonates, 17 in 2004 and 19 in 2005. Mean birth date in 2004 was later ($t_{34} = -2.64$; $P = 0.012$; 15 Aug) than in 2005 (4 Aug); however, mean birth mass did not differ ($t_{34} = 0.14$; $P = 0.893$) between years (2004: $\bar{x} = 2.50$ kg, SE $= 0.19$; 2005: $\bar{x} = 2.53$ kg, SE $= 0.11$; range for both yr = 1.35–4.10 kg). Overall survival for the first 8 weeks of life was 33.3%. Although survival in 2005 (42.1%) tended to be greater than 2004 (23.5%), it was not significant ($\chi^2 = 1.39$; $P = 0.238$). The most common cause of mortality during both years (41.7%) was predation by coyotes (*Canis latrans*), followed by emaciation (25.0%), possible predation (20.8%), and accidents and unknown causes ($<$13.0%; Table 1). When comparing maternal condition among neonates with different fates, we did not detect any differences ($P > 0.050$) in age or chest girth of

Table 1. Causes of mortality of neonatal white-tailed deer (2004–2005) during the initial 8 weeks of life in Auburn, Alabama, USA.

	2004		2005	
Cause of mortality	**%**	***N***	**%**	***N***
Predation	38.5	5	45.5	5
Possible predation	7.7	1	36.4	4
Emaciation	46.2	6	0.0	0
Accident[a]	0.0	0	9.1	1
Unknown	7.7	1	9.1	1

[a] Neonate fell in hole soon after birth and could not escape.

mothers for neonates that died due to emaciation (age = 3.83 yr, chest girth = 832.50 mm), neonates that died of all other causes (age = 3.33 yr, chest girth = 809.72 mm), and neonates that survived (age = 3.58 yr, chest girth = 845.83 mm).

From the known-fate analysis the best model (AIC_c relative wt [AIC_w] = 0.43) from the set of candidate models was the additive model of the linear time trend, mass, and year (Table 2), suggesting that the change in weekly survival was a linear function of time and varied between years and between masses at an equal rate. The second-best model ($\Delta AIC_c = 0.61$, $AIC_w = 0.31$), the additive model of the linear time trend and mass, also had some strength of evidence as a plausible model. Therefore, we determined parameter likelihoods, estimates, and standard errors using model averaging. The parameter likelihoods illustrated that the linear time trend (likelihood = 0.92; estimate = 0.29; SE = 0.01), mass (likelihood = 0.81; estimate = 0.43; SE = 0.22), and year (likelihood = 0.58; estimate = −0.23; SE = 0.17) were the most important parameters to be included in the best model. From the top model we determined that survival each week following birth increased by a factor of 1.36, although not significantly (95% CI = 0.08–2.63). Similarly, survival increased by 1.69 with each additional kilogram of birth weight (95% CI = 0.07–3.31) and neonates born in 2005 were 1.49 times more likely to survive than neonates born in 2004 (95% CI = −0.11–3.09), both of which were not significant. Models containing the variables age of the mother, birth date, sex, and time following birth did not explain a significant proportion of variation in survival (Table 2). Parameter likelihoods (<0.01) also indicated that age of the mother, birth date, sex of neonate, and time following birth were not likely to be included in the best model. The Hosmer–Lemeshow goodness-of-fit statistic ($\hat{c} = 0.714$) indicated that the most general model fit the data well.

DISCUSSION

We found mortality of exurban neonatal white-tailed deer in our study to be 66.7%, of which 41.7–62.5% of total mortalities were attributed to predation by coyotes. Our neonatal mortality rate was greater than the mean rate among temperate ungulates (45%) as calculated by Linnell et al. (1995) and among studies of white-tailed deer in rural areas (range: 23.6–90.0%, $\bar{x} = 54.8\%$). Additionally, 69% of these studies resulted in mortality lower than the rate observed in this study (Cook et al. 1971: 71.6%, Garner et al. 1976: 82.9%, Carroll and Brown 1977: 40.8%, Bartush and Lewis 1981: 90.0%, Epstein et al. 1985: 84.4%, Huegel et al. 1985: 23.6%, Nelson and Woolf 1987: 30.0%, Kunkel and Mech 1994: 42.9%, Sams et al. 1996: 38.2%, Long et al. 1998: 59.0%, Ballard et al. 1999: 44.0%, Ricca et al. 2002: 58.7%, Vreeland et al. 2004: 48.6%). The relatively high rate of neonatal mortality we observed in this study could be attributed to several reasons, including a function of sampling biases of other studies and higher predation rates due to sparse bedding cover and late birthing season. Because most previous studies on neonatal survival of white-tailed deer captured neonates with foot searches or female behavior, most neonates were a few days to weeks old at time of capture. Therefore, mortality occurring within the first few days of life went undetected and could have resulted in lower rates. In our study, 50.0% of mortalities occurred in the first week of life. Therefore, to accurately measure survival, it is critical that neonates are captured as early as possible or analyses account for staggered entry of individuals into survival models (Pollock et al. 1989).

We also attribute the high mortality we detected to a high coyote predation rate on this population. Other studies have detected similar coyote predation rates (>50.0% predation rate, of which >50% attributed to coyotes) of neonatal white-tailed deer in various geographic regions of the United States, including Oklahoma (Garner et al. 1976), Iowa (Huegel et al. 1985), Illinois (Nelson and Woolf 1987), and Texas (Cook et al. 1971, Carroll and Brown

Table 2. Model results from known-fate analysis of survival rates during the initial 8 weeks of life for neonatal white-tailed deer in Auburn, Alabama, USA, from 2004–2005.

Model	No. parameters	ΔAIC_c[a]	AIC_w[b]
S (linear time trend + yr + mass)[c]	4	0.00	0.43
S (linear time trend + mass)	3	0.61	0.31
S (linear time trend + yr)	3	2.93	0.10
S (linear time trend)	2	3.25	0.08
S (yr + mass)	3	5.06	0.03
S (mass)	2	6.77	0.01
S (yr × mass)[d]	4	6.85	0.01
S (time + yr + mass)	10	9.42	0.00
S (time + mass)	9	9.59	0.00
S (yr)	2	9.60	0.00
S (.)[e]	1	11.12	0.00
S (time)	8	11.80	0.00
S (time + yr)	9	11.85	0.00
S (sex of neonate)	2	12.50	0.00
S (birth date)	2	12.93	0.00
S (age of mother)	2	13.14	0.00
S (time + age of mother)	9	14.02	0.00
S (time × yr)[f]	16	19.83	0.00

[a] Difference between model's Akaike's Information Criterion corrected for small sample size and the lowest AIC_c value.
[b] AIC_c relative wt attributed to model.
[c] Model of additive effects of linear time trend, yr, and mass.
[d] Model of additive effects of yr and mass and the interaction.
[e] Model of no effects on survival.
[f] Numerical convergence not reached.

1977). We suspect that the high rate of predation was due to efficient detection of bedded or nursing neonates in the open landscape of the exurban area. During the study, the majority of neonates that we captured inhabited and bedded in areas of sparse cover (i.e., wooded yards with open understory, hedge rows, landscaping near homes, etc.). Coyotes are visual hunters, and therefore it has been suggested that increased predation on neonatal white-tailed deer by coyotes is associated with sparse vegetative cover (Garner et al. 1976, Carroll and Brown 1977, Huegel et al. 1985, Nelson and Woolf 1987, Long et al. 1998). This effect would be most evident within the first 30 days of life because neonates spend much of their time bedded and therefore rely on camouflage to avoid predation (Huegel et al. 1985). The timing of the birthing season in this population could also have contributed to increased predation. In Alabama, the birthing season is much later than in other populations of white-tailed deer, occurring from late July to early September (Gray et al. 2002). This birthing season coincides with the greatest hunting population of coyotes because predispersal coyote pups are hunting independently at this time (Harrison and Harrison 1984, Harrison et al. 1991).

The second major cause of mortality in this population (25.0%) was emaciation. This cause, while relatively high (46.2%) in the first year, was absent in the second. Although there are numerous potential causes for emaciation, we believe the mostly likely cause in our study was abandonment. However, we were unable to determine the cause of abandonment. Potential causes include the neonate being unable to nurse, the female never returning, or the female being unable to return. However, we were able to relocate most females and, therefore, could eliminate the possibility of mortality of the mothers in most cases. Although handling-induced abandonment is a potential cause, Carstensen Powell et al. (2005) noted that increased scent transfer, increased handling time, time of capture, and increased handling stress of neonates did not influence abandonment in a free-ranging herd of white-tailed deer in Minnesota, USA. Because many of the neonates that died due to emaciation in our study were in close proximity (<30 m) to a heavily used paved biking and walking trail, we speculate that high human activity near birth sites, as found in many exurban areas, may interfere with mothers being able to return to bedded neonates and could increase rates of abandonment.

Although we had originally hypothesized that vehicular accidents would be a contributing mortality factor, we did not detect any neonatal mortality due to vehicles in our study. Vehicular accidents have been determined to be a major cause of mortality of adult white-tailed deer living in urban and suburban areas (66% of mortality, Etter et al. 2002; 73% of mortality, Hansen and Beringer 2003). However, we speculate that the sedentary nature of neonates early in life (at 4–8 weeks of age they are active only 15–20% of the time [Jackson et al. 1972]) may have resulted in neonates only infrequently crossing roads.

As with several other studies on white-tailed deer, we noted that survival was positively associated with time following birth (Garner et al. 1976, Nelson and Mech 1986, Long et al. 1998, Ricca et al. 2002, Vreeland et al. 2004) and birth mass (Verme 1962, 1977; Nelson and Woolf 1987; Kunkel and Mech 1994; Vreeland et al. 2004). Because the leading causes of mortality for this population were predation and emaciation, these results suggest that neonates are more susceptible to these causes of mortality earlier in life. Additionally, in a study done in Pennsylvania, USA, on neonatal white-tailed deer, Vreeland et al. (2004) noted similar results in that neonates were 2.14 times more likely to survive with each additional kilogram of weight at capture. It should be noted, however, that because we waited 4 hours after birth to capture neonates, most neonates would have been nursed prior to capture. The amount of milk contained within the rumen could affect birth weights. However, as is the case in most wildlife studies where complete control of the study animals is impossible, we could not determine the amount of feeding prior to weighing and our estimates of body mass contain the normal variability that would be expected due to variation in feeding and capture times of free-ranging animals.

MANAGEMENT IMPLICATIONS

As one of the fastest growing landscapes around the world, exurbia has the potential to greatly impact wildlife species inhabiting these areas. Because of this, understanding differences between wildlife in rural and exurban areas is essential for management decisions. Our results indicate that coyote predation may be a significant source of natural mortality for neonatal white-tailed deer in this environment. Although normally considered to be a hindrance to management goals for white-tailed deer, coyotes and their predation on neonatal deer should be considered an integral part of any population control strategy in the exurban landscape.

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