Influence of urbanization on white-tailed deer fawn survival and cause-specific mortality

Kyle Zampogna

April 15th, 2025

Submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Masters of Fisheries Wildlife, and Conservation Biology

Committee:
Dr. Lara Pacifici, Chair
Dr. Christopher Moorman
Dr. Nathan Hostetter

Introduction:

As human populations grow, cities expand and habitat for wildlife is fragmented, altered, and/or entirely replaced by urban infrastructure. The global human population of all urban areas is projected to grow to 5 billion by 2030, and urban land cover is projected to occupy three times the land surface that was covered in 2000 (Seto et al. 2012, Venter et al. 2016).

More specifically, urbanization affects white-tailed deer (*Odocoileus virginianus*; hereafter "deer") ecology in a number of ways. The habitat fragmentation that accompanies urbanization affects deer movement and space use by forming barriers to movement (Anderson et al. 2011). Urban deer may have different diets tha rural deer because of the increase in human-supplied foods and greater ornamental browse in urban landscapes. Disease rates may be higher due to greater deer densities in urban landscapes (Farnsworth et al. 2005). Deer-vehicle collisions may be greater and predation mortality lower in urban landscapes than in rural landscapes.

Neonatal deer survival may vary regionally or locally based on predator densities and the distribution of concealing vegetation, (Gaillard et al. 2000, Chitwood et al. 2015, Chitwood et al. 2017), but few studies have investigated fawn survival in urban or exurban populations (Saalfeld et al. 2007, Piccolo et al. 2010, Gingery et al. 2018). Fawn survival may vary across the urbanization gradient due to variation in predator density, disease prevalence, food availability, cover availability, and risks posed by humans (i.e., interacting with bedding fawns, car collisions) across the gradient.

Our objectives were to estimate fawn survival across the urbanization gradient, and assess potential relationships between survival and urbanization, sex, birth timing, and fawn age. We predicted that:

(1) fawn survival to recruitment age (16 weeks of age) would increase with greater urbanization,

(2) predation rates would decrease with increasing urbanization, and

(3) more human-caused mortality, especially vehicle collisions, would occur in more urban areas of the study area.

Methods:

Study Area

We monitored white-tailed deer fawns in Durham and Orange counties, North Carolina, across an approximately 772-km^2 study area (Figure 1). The study area featured a gradient of urbanization, from high-density residential neighborhoods and commercial development to landscapes dominated by agriculture and forest.

Doe capture and handling

We captured adult female deer at least one year old at sites baited with whole kernel corn via drop netting or tranquilizer darts from January to April, 2022 - 2024 across the urbanization gradient (Figure 1). We immobilized captured deer with butorphanol–azaperone–medetomidine (BAM, Wildlife Pharmaceuticals, Windsor, Colorado). We fitted captured females with Global Position System (GPS) collars (Model G5-2D; Advanced Telemetry Systems [ATS], Isanti, MN), and vaginal implant transmitters (VITs ; Model M3930U, ATS) to monitor location and record timing of birthing. During parturition, expelled VITs emitted a signal signifying that birth had occurred. Advanced Telemetry Systems' Neolink system was used to monitor satellite messages emitted by VITs upon parturition.

Fawn Handling

Upon receiving a "birth signal," from a VIT, we waited at least 4 hours before initiating the search for fawns. This delay allowed for regular grooming and bonding to occur between females and their fawns. We used handheld forward-looking infrared (FLIR) units to aid in the search for fawns (Haskell et al. 2007). Additionally, we opportunistically captured fawns using grid searches in targeted areas during the parturition period. We aged opportunistically captured fawns using hoof growth measurements (Haugen and Speake 1958, Haskell et al. 2007).

Upon locating a fawn, we recorded sex, mass, hoof growth measurement, and location. We fitted fawns with expandable breakaway GPS collars (Model W500-EAA, ATS) or VHF collars (Model M4210, ATS).

Fawn monitoring and fate determination

We monitored fawns via telemetry from capture until 16 weeks of age (112 days) or death. We considered fawns recruited to the huntable population at 16 weeks of age (Kilgo et al. 2012). Fawns were monitored twice daily - once around 6:00 am and again around 4:00 pm. Frequent monitoring allowed for precise detection of mortality, enabling rapid response and examination of fawn remains, which reduced the potential for scavenging to disturb the condition or location of carcasses (Cook et al. 1971, Kilgo et al. 2012, Chitwood et al. 2015).

Upon locating a fawn carcass or collar, an initial field evidence-based cause of mortality was assigned. Tracks, scat, condition or caching of fawn remains, bite mark characteristics, location of recovery, and other relevant evidence were considered when making this initial assessment. Predator saliva samples were collected from bite wounds, feeding sites on fawncarcasses, and the head and collar of the fawn for DNA analysis to determine predator species. This DNA analysis was performed by the North Carolina Wildlife Resources Commission's wildlife forensics laboratory. The Southeastern Cooperative Wildlife Disease

Study (SCWDS) – Wildlife Services Lab evaluated whole carcasses when the cause of mortality was unclear.

Quantifying urbanization

We used the percentage of impervious surface surrounding the birth site as a quantitative proxy for urbanization across the urbanization gradient. We used the 2021 National Land Cover Database (NLCD) impervious surface raster to quantify urbanization across the gradient (Dewitz, 2021). The NLCD raster has a 30x30 meter resolution. To incorporate the broader surroundings beyond individual grid squares, we calculated the average impervious surface percentage within the 1-km^2 area surrounding each grid square and assigned this averaged value to each respective grid square. We used 1 km^2 because this was approximately the average homerange size for female deer in our study (M. Carver, North Carolina State University, unpublished data). The averaged value of the grid square in which a fawn was born was assigned to the fawn as a measurement of the level of urbanization of the landscape used by a fawn and doe.

Model construction

We evaluated factors that influenced fawn survival and cause-specific mortality using a known-fate survival model in a Bayesian framework. We used a staggered entry modeling approach where each fawn entered the model at its capture date. The endpoint for an individual corresponded to a mortality event, collar malfunction (censored), or 16 weeks of age.

We modeled the state (alive or dead) of fawn i on day k ($z[i,k]$) as a series of Bernoulli trials, where $S[i,k]$ is the daily survival probability for individual i on day k. We modeled daily survival as a function of urbanization (quantified by impervious surface), fawn sex, age (in days postpartum), and birthdate deviation from median birthdate for an individual's birth year.

Conditional on death, we modeled cause specific mortality as a Bernoulli random variable where death was either due to predation or non-predation mortality.

We fit our model in JAGS (Plummer 2003) using the “jagsUI” package (Kellner 2023) in R (version 4.4.1, R Core Team 2024). Each model was run for 12,000 iterations with a 2,000 burn in and a thin rate of 2. We summarize results as posterior means and 95% credible intervals (95%CrI).

Results:

We captured and radio-collared 37, 39, and 36 white-tailed deer fawns in 2022, 2023, and 2024, respectively (Figure 1, Table 1). Of the 112 fawns collared, 4 were right-censored due to premature collar breakoffs (n = 2), or inability to receive signal (n = 2). Fawns were left-censored to account for unknown survival status prior to capture. These fawns were included in the survival analysis only from the time they were first observed and collared.

Table 1: Known fates and % of total for collared white-tailed deer fawns to 16 weeks of age in Durham and Orange Counties, North Carolina, 2022–2024. We observed 66 mortalities from the monitoring of 108 total fawns to 16 weeks of age (2022 = 34 fawns, 2023 = 38 fawns, 2024 = 36 fawns). “Confirmed coyote predation” events were classified as such when field evidence was sufficient to clearly indicate coyote predation and/or and PCR results included coyote DNA. When mortality investigations found evidence of predation, but site evidence and DNA results were inconclusive, mortalities were classified as “Predation - unconfirmed predator”.

Cause of mortality	2022		2023		2024		Total	
	n	%	n	%	n	%	n	%
Survival to 16 Weeks Of Age	14	43.8%	12	31.6%	14	38.9%	40	37.7%
Confirmed Coyote Predation	9	28.1%	19	50.0%	11	30.6%	39	36.8%
Predation - unconfirmed predator	4	12.5%	1	2.6%	4	11.1%	9	8.5%
Abandonment / Malnutrition	2	6.3%	3	7.9%	2	5.6%	7	6.6%
Disease	1	3.1%	1	2.6%	2	5.6%	4	3.8%
Injury	0	0.0%	2	5.3%	1	2.8%	3	2.8%
Vehicle collision	2	6.3%	0	0.0%	1	2.8%	3	2.8%
Unknown	0	0.0%	0	0.0%	1	2.8%	1	1.0%
Total	32		38		36		106	

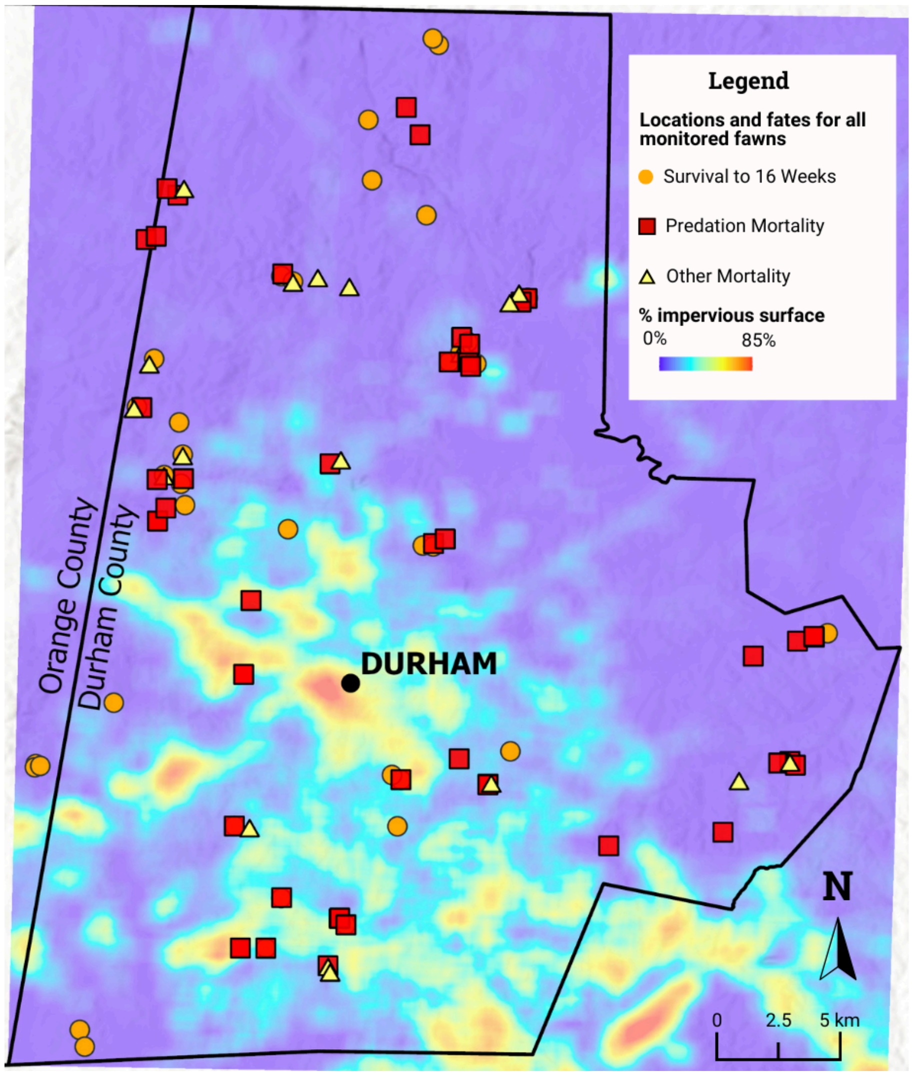

Figure 1: Birth sites and 16 week fates of 108 white-tailed deer fawns along the urbanization gradient in Durham and Orange counties, North Carolina, during 2022 - 2024.

Daily survival probability increased as fawns aged (Figure 2). Nearly half (42.2%; 28 of 66) of all mortalities occurred during the first 14 days postpartum. Over the next 21 days, from 15 days postpartum to 35 days postpartum, 31.8% of all mortality (21 of 66) occurred. Nearly all non-predation mortality occurred in the period from 0 - 35 days postpartum. Lower rates of mortality (25.8%, 17 of 66) occurred from 36 days to the end of the observation period (day 112 postpartum), and most (88.2%; 15 of 17) of the mortality occurring after 36 days was due to predation. The two non-predation mortalities that occurred after 36 days postpartum were from vehicle collisions.

Survival probability to recruitment age did not vary with percent impervious surface surrounding birth site (urbanization); however, the probability of coyote predation as the cause of mortality increased with urbanization (Tables 2 and 3; Figure 3). Fawn sex had no effect on probability of survival to recruitment age or cause of mortality (Tables 2 and 3).

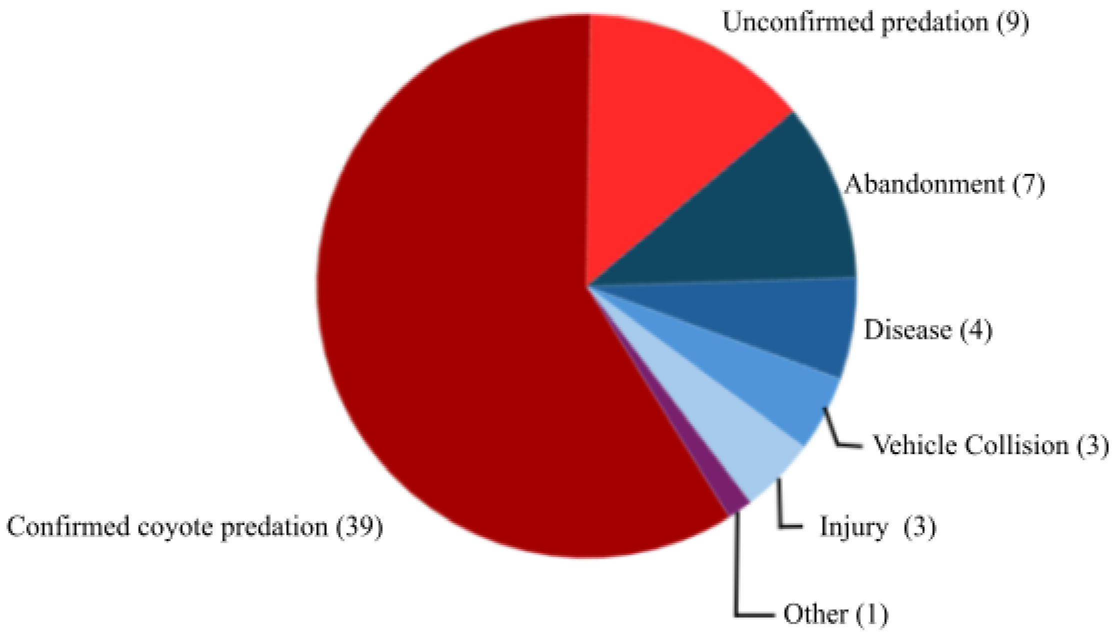

Figure 2: Causes of fawn mortality across the urbanization gradient in Durham and Orange counties, North Carolina, 2022-2024. Predation accounted for 48 mortalities (72.7%), while non-predation causes of mortality, (including abandonment (7), disease (4), vehicle collisions, other non-predation injuries (3), and an unknown, non-predation mortality) accounted for18 mortalities (27.3%).

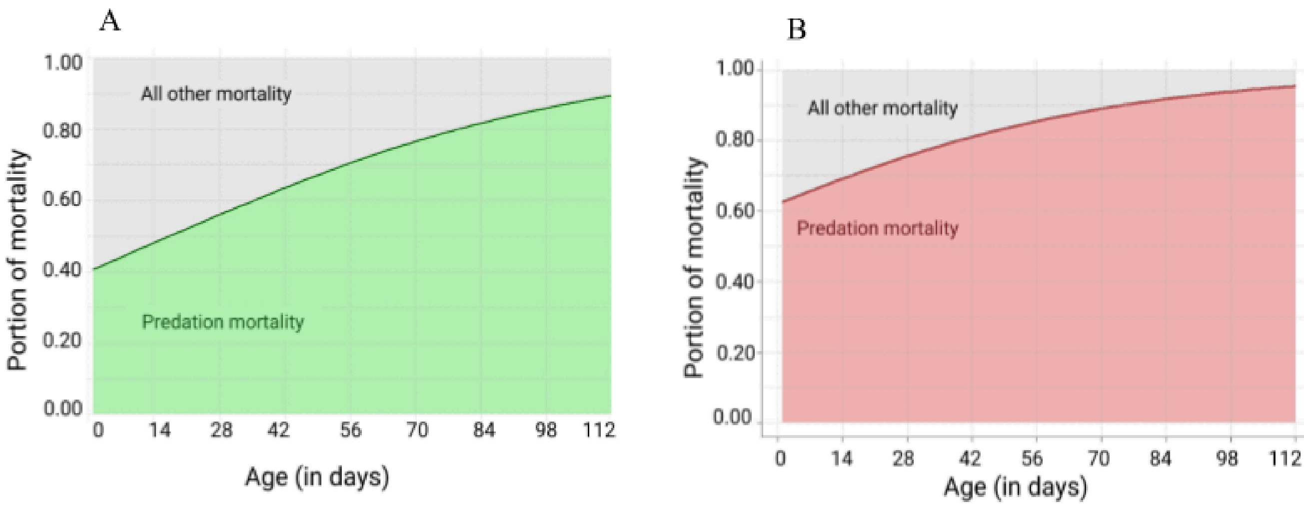

Figure 3: Predation mortality and all other causes of mortality at (A) 25th percentile (more rural) for impervious surface, and (B) 75th percentile (more urban) for 1 km^2- smoothed impervious surface coverage.

Table 2: Parameter estimates and 95% credible intervals for daily white-tailed deer fawn survival in Durham and Orange Counties North Carolina (2022-2024).

Parameter	Parameter estimate	Standard Deviation	2.50%	97.50%
Baseline parameter	3.64	0.25	3.17	4.16
Age parameter	0.03	0.01	0.02	0.04
Sex parameter	-0.08	0.26	-0.59	0.42
Urbanization parameter	-0.13	0.13	-0.38	0.14
Birth timing parameter	0.22	0.15	-0.07	0.51
Birth timing parameter (quadratic term)	0.02	0.09	-0.14	0.21

Table 3: Parameter estimates and 95% credible intervals for the probability of predation as cause of mortality for white-tailed deer fawns in Durham and Orange counties, North Carolina, 2022-2024.

Parameter	Parameter estimate	Standard Deviation	2.50%	97.50%
Baseline parameter	0.17	0.60	-1.00	1.34
Age parameter	0.02	0.01	0.00	0.06
Sex parameter	0.75	0.63	-0.49	2.00
Urbanization parameter	0.80	0.45	0.03	1.79
Birth timing parameter	0.82	0.53	-0.10	1.97
Birth timing parameter (quadratic term)	0.61	0.40	-0.07	1.49

Discussion:

Despite variation in causes of mortality along the urban-rural gradient, fawn survival rates did not vary along the gradient. Due to the role that fawn survival plays in population dynamics, this finding should be considered when modeling deer population growth in urbanizing areas. Our observed survival rate to 16 weeks (0.389) was slightly higher than the survival rate reported in another urban / exurban fawn survival study in Alabama (0.33 survival rate to 8 weeks of life) (Saalfeld et al. 2010). The fawn survival rate we observed was higher than fawn survival rates reported in the region (Kilgo et al. 2012, Chitwood et al. 2015).

Increased predator efficiency or density in urban areas may explain the increase in probability of death due to predation in the more urban areas of the study. Urban patches with vegetation present used for fawning cover in urban areas often are smaller and more isolated than rural vegetated patches and facilitate more efficient predator movement (Atwood et al. 2010). Trails for human use are common in forested urban patches, and may serve as travel corridors for predators (Sinclair et al. 2005). In urban areas, understory structure is reduced or absent, and rarely present in continuous patches (Brown and Anand 2024). This lack of understory structure may negatively affect the ability of fawns and their mothers to avoid detection by predators (Kilgo et al. 2010). Predator density throughout the study area was unknown,

The positive relationship between fawn age and survival rate across the urbanization gradient is consistent with other fawn survival analysis. Daily survival increased as fawns developed physiologically and behaviorally, becoming more resistant to disease, less maternally reliant, and more able to evade predators. Additionally, fawn susceptibility to disease and malnutrition (due to maternal abandonment) decreases as fawns age. Although predation poses a risk to fawns throughout the first 16 weeks postpartum, individuals rely less on crypsis and use mobility to escape coyote predation (Lent 1974).

We did not find that fawns born nearer to the median birth date in a given year had higher survival rates or different susceptibility to predation. Model results indicated a weak positive relationship between birth timing and fawn survival, showing that later-born fawns had a greater probability of survival.

Sex did not affect survival and cause of mortality. This is likely because male and female fawns are ecologically similar during early life stages, exhibiting very similar behavior, space use, and vulnerability to environmental risks. As a result, both sexes are exposed to similar levels of predation, disease risk, and other mortality factors, leading to no substantial differences in survival outcomes.

As urban areas continue to expand, wildlife are forced to adapt to novel environments with altered predator communities, habitat structure, and human activity. Our finding that landscape features associated with urbanization did not affect fawn mortality rates can inform deer population projections in urbanizing areas. Our findings also highlight urbanization as a factor affecting white-tailed deer population dynamics into the future, as more of the species' range becomes urban.

References:

Anderson, C. W., C. K. Nielsen, D. J. Storm, and E. M. Schauber. 2011. Modeling habitat use of deer in an exurban landscape. Wildlife Society Bulletin 35:235–242.

Atwood, T.C., H.P. Weeks, T.M. Gehring. 2004. Spatial ecology of coyotes along a suburban-to-rural gradient. The Journal of Wildlife Management 68(4), 1000-1009.

Brown, M. L., M. Anand. 2024. Impacts of urban land-cover on plant community structure and biodiversity in a multi-use landscape. Landscape Ecology. 39: 197.

Chitwood, M. C., M. A. Lashley, J. C. Kilgo, C. E. Moorman, and C. S. DePerno. 2015. White-tailed deer population dynamics and adult female survival in the presence of a novel predator. The Journal of Wildlife Management 79:211–219.

Chitwood, M. C., M. A. Lashley, C. S. DePerno, and C. E. Moorman. 2017. Considerations on neonatal ungulate capture method: potential for bias in survival estimation and cause-specific mortality. Wildlife Biology.

Cook, R. S., M. White, D. O. Trainer, and W. C. Glazener. 1971. Mortality of young white-tailed deer fawns in south Texas. The Journal of Wildlife Management. 35:47–56.

Dewitz, J. 2021. National Land Cover Database (NLCD) 2019 Land Cover Science Product (ver. 2.0, June 2021). U.S. Geological Survey data release.

Farnsworth, M. L., L. L. Wolfe, N. T. Hobbs, K. P. Burnham, E. S. Williams, D. M. Theobald, et al. 2005. Human land use influences chronic wasting disease prevalence in mule deer. Ecological Applications 15:119–126.

Gaillard, J.-M., M. Festa-Bianchet, N. G. Yoccoz, A. Loison, and C. Toïgo. 2000. Temporal variation in fitness components and population dynamics of large herbivores. Annual Review of Ecology and Systematics 31:367–393.

Gingery, T. M., D. R. Diefenbach, B. D. Wallingford, and C. S. Rosenberry. 2018. Landscape-level patterns in fawn survival across North America. The Journal of Wildlife Management 82:1003–1013.

Haskell, S. P., W. B. Ballard, M. C. Wallace, R. T. Bowyer, and M. H. Humphrey. 2007. Observations on capturing and aging deer fawns. Journal of Mammalogy 88:1482–1487.

Haugen, A. O., and D. W. Speake. 1958. Determining age of young fawn white-tailed deer. The Journal of Wildlife Management 22:319–320.

Kellner, K. 2024. jagsUI: A wrapper around 'rjags' to streamline 'JAGS' analyses. R package version 1.6.2.

Kilgo, J. C., H. S. Ray, C. Ruth, and K. V. Miller. 2010. Can coyotes affect deer populations in southeastern North America? The Journal of Wildlife Management 74:929–933.

Kilgo, J. C., H. S. Ray, M. Vukovich, M. J. Goode, and C. Ruth. 2012. Predation by coyotes on white-tailed deer neonates in South Carolina. The Journal of Wildlife Management 76:1420–1430.

Kilgo, J. C., M. Vukovich, H. S. Ray, C. E. Shaw, and C. Ruth. 2014. Coyote removal, understory cover, and survival of white-tailed deer neonates. The Journal of Wildlife Management 78:1261–1271.

Lent, P.C. 1974. Mother-Infant Relationships in Ungulates. IUCN Publications, 14-55.

Michel, E. S., B. E. McMillan, K. J. Jenkins, and D. R. Diefenbach. 2020. Relative reproductive phenology and synchrony affect neonate survival in a non-precocial ungulate. Functional Ecology 34:2536–2547.

Piccolo, B. P., J. L. Cornicelli, D. T. Cooper, M. W. Sears, and K. M. Carstensen. 2010. Behavior and survival of white-tailed deer neonates in two suburban forest preserves. Canadian Journal of Zoology 88:487–495.

Plummer, M. 2003. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. 3rd International Workshop on Distributed Statistical Computing (DSC 2003), Vienna, Austria.

Potratz, E. J., J. S. Brown, T. Gallo, C. Anchor, and R. M. Santymire. 2019. Effects of demography and urbanization on stress and body condition in urban white-tailed deer. Urban Ecosystems 22:807–816.

R Core Team. 2024. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Saalfeld, S. T., and S. S. Ditchkoff. 2007. Survival of neonatal white-tailed deer in an exurban population. The Journal of Wildlife Management 71:940–944.

Seto, K. C., B. Güneralp, and L. R. Hutyra. 2012. Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. Proceedings of the National Academy of Sciences 109:16083–16088.

Sinclair, K. E., G. R. Hess, C. E. Moorman, and J. H. Mason. 2005. Mammalian nest predators respond to greenway width, landscape context and habitat structure. Landscape and Urban Planning. 71:277–293.

Venter, O., E. Sanderson, A. Magrach, et al. 2016. Sixteen years of change in the global terrestrial human footprint and implications for biodiversity conservation. Nature Communications 7:12558.