Research Article

Space Use and Survival of White-Tailed Deer in an Exurban Landscape

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ABSTRACT Exurban development is nonmetropolitan, residential development characterized by a human population density and average property size intermediate between suburban and rural areas. Although growth in exurban areas is outpacing that of urban, suburban, or rural landscapes, studies of deer (*Odocoileus* spp.) ecology in exurban areas are nonexistent. During 2003–2005, we studied space use (i.e., seasonal home-range and core-area size and habitat use relative to human dwellings) and survival of 43 female white-tailed deer (*O. virginianus*) in an exurban setting near Carbondale, Illinois. Deer had larger home ranges than most suburban deer populations and generally smaller home ranges than rural deer populations. When we analytically controlled for habitat use, deer exhibited a subtle avoidance of human dwellings, especially during the fawning season. The annual survival rate was among the highest reported in the literature at 0.872 (SE = 0.048). Only 5 deer (cause-specific mortality rate = 0.091) were harvested by hunters, indicating major obstacles for wildlife managers when attempting to manage deer in exurban areas using traditional hunter harvest. (JOURNAL OF WILDLIFE MANAGEMENT 71(4):1170–1176; 2007)

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Exurbia is residential land use outside of city limits that is situated among working farms or undeveloped land, with a human population density and average property size intermediate between the suburbs and rural areas (Nelson 1992). From an ecological perspective, the important distinction between exurban and suburban landscapes is that human dwellings in exurbia are generally interspersed throughout wildlife habitat rather than habitat existing in patches (e.g., municipal parks) within suburban nonhabitat (Odell and Knight 2001). Due to its more dispersed pattern, residential development in exurbia has a greater impact on the landscape on a per-unit basis than suburban and urban growth patterns (Theobald et al. 1997).

An estimated 10 million people were added to exurbia in the United States during the 1990s, more than were added to urban, suburban, or rural landscapes (Nelson and Sanchez 2005). Because exurbia is expanding at a greater rate than other types of human development, its potential impact on the ecology and management of white-tailed deer (*Odocoileus virginianus*) is likely considerable and deserves research attention. Although deer ecology and management has been studied extensively in urban and suburban landscapes (Cornicelli et al. 1996, Kilpatrick and Spohr 2000, Etter et al. 2002, Grund and Woolf 2002, Grund et al. 2002, Porter et al. 2004), deer space-use and survival in exurbia has not been explicitly studied.

The landscape changes resulting from exurban development and the presence of a relatively high human population result in a high potential for conflict between humans and deer. Studies of suburban deer have indicated that deer easily habituate to human development and readily use residential areas if sufficient cover is available (Swihart et al. 1995, Kilpatrick and Spohr 2000, Grund et al. 2002). Deer appear to avoid human development to some extent when possible (Swihart et al. 1995, Kilpatrick and Spohr 2000, Grund et al. 2002). However, in some cases, deer may have little choice but to exploit heavily developed areas, and have clearly done so successfully (Swihart et al. 1995, Kilpatrick and Spohr 2000, Grund et al. 2002). The dispersed, low-density development in exurbia may allow deer some degree of choice in the intensity of space-use near human dwellings. Although deer should be able to avoid dwellings if they are disturbed by them, or if habitat near homes is of low suitability, no studies have directly tested these hypotheses. Furthermore, knowledge of deer space-use relative to human dwellings is necessary to determine how deer respond to development and should help predict the extent to which deer–human conflicts will occur in exurban landscapes.

Survival of suburban deer is typically high due to the lack of hunting and natural predators (Etter et al. 2002). For instance, deer in the forest preserves of the Chicago, Illinois, USA metropolitan area suburbs had an annual survival rate of 82%; the dominant form of mortality was deer–vehicle collisions (DVCs; Etter et al. 2002). Hunting is generally legal in exurbia, although relatively few properties may actually be hunted (Storm et at. 2007). Further, county-level harvest efficiency can be inversely related to nonmetropolitan development (Harden et al. 2005). Therefore, it is important to determine the extent to which the reduced

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proportion of hunted properties affects deer survival in exurbia because it directly affects the ability of deer biologists to manage deer through hunter harvest.

We studied deer in an exurban setting near Carbondale, Illinois, to address the aforementioned paucities in the literature. Our objectives were to quantify 1) seasonal home-range and core-area sizes, 2) density of human dwellings within seasonal home ranges and core areas, 3) habitat use relative to human dwellings, and 4) annual survival rate and cause-specific mortality. Our goal was to provide wildlife biologists with information useful for understanding deer ecology and the potential challenges to deer management in exurbia.

STUDY AREA

We studied deer in an exurban setting southeast of Carbondale, Illinois, in Jackson and Williamson Counties. Summers in the region were hot and humid (31° C $\bar{x}$ Jul high temp, 116.5 cm annual precipitation); winters were mild (–6.2° C $\bar{x}$ Jan low temp; Midwestern Regional Climate Center 2005). The study area encompassed nearly 18 km^2 and contained 357 dwellings (20 dwellings/km^2) arranged in a clumped distribution. Three major roads with speed limits $>$64 km per hour ran through the study area; road density was 1.5 km per km^2 (Illinois Department of Natural Resources 1996).

METHODS

Study Area Delineation and Landcover Map Construction

We delineated study area boundaries using a minimum convex polygon (Mohr 1947) of all recorded deer locations and buffered by 200 m. We used the database of rural structures compiled by Harden (2002) to map human dwellings on the study area and updated the database with a hand-held Global Positioning System (GPS) unit as needed.

We created a landcover map for the study area by manually digitizing landcover polygons onto Digital Orthophoto Quarter Quadrangles (DOQQs) in Arc View 3.2. We used DOQQs and ground-truthing to delineate cover types. Six cover types—forest, grassland, cropland, oldfield, wetland, and urban—comprised 59%, 25%, 11%, 3%, 1%, and 1% of the study area, respectively. The primary landscape change that accompanied exurban development on the study area was fragmentation of forest patches.

We classified land with an overstory of trees as forest. Forest understory vegetation ranged from nonexistent to very dense. *Quercus* spp. and *Carya* spp. dominate southern Illinois woodlands (Neely and Heister 1987). Grassland on the study area consisted of hayfields, lawns, and idle grass fields with little or no encroachment by woody plants. Fescue (*Festuca* spp.) was a dominant grass on the study area. We classified row-crop agriculture fields as cropland. Crops grown on the study area consisted entirely of soybeans during the study. We considered areas with no overstory but with a dense understory of herbaceous vegetation and woody plants to be oldfield. Autumn olive (*Elaeganus umbellata*), blackberry (*Rubus* spp.), honeysuckle (*Lonicera japonica*), goldenrod (*Solidago* spp.), multiflora rose (*Rosa multiflora*), and sweet clover (*Melitotus* spp.) were common plant species in oldfields. Any nonflowing water body holding water most of the year was classified as a wetland. The majority of wetlands in the study area were man-made ponds. We classified areas of concentrated buildings or large parking lots as urban.

Deer Capture and Radiotelemetry

We captured deer during October 2002–March 2003, September 2003–March 2004, and October 2004–January 2005. We baited deer to capture sites with corn and apples and captured deer via tranquilizer darting (Pneu-dart Inc., Williamsport, PA), drop-nets (Ramsey 1968), and rocket-nets (Hawkins et al. 1968). We immobilized darted deer with an intramuscular injection (3 mL) of a 2:1 mix of Telazol® (Tiletamine HCl, 2mg/kg; and Zolazepam HCl, 4 mg/kg; Ford Dodge Animal Health, Fort Dodge, IA) and Rompun® (Xylazine HCl, 2 mg/kg; Bayer Corp., Shawnee Mission, KS). We immobilized deer captured in nets intramuscularly with a hand injection of Ketaset (Ketamine HCl, 10mg/kg; Fort Dodge Animal Health). We fit either very high frequency (VHF) radiocollars (Advanced Telemetry Systems, Inc., Isanti, MN) weighing 500 g each or GPS collars (Telonics, Inc., Mesa, AZ) weighing 700 g each on females only. We programmed GPS collars to obtain locations at either 1-hour or 2-hour intervals and to detach from deer after a period of 5–6 months for collars obtaining hourly locations or 10–12 months for collars obtaining bihourly locations. We captured and handled deer in accordance with methods approved by the Institutional Animal Care and Use Committee at Southern Illinois University Carbondale (protocol no. 03-003).

We located VHF-collared deer using standard, ground-based radiotelemetry (White and Garrott 1990). We obtained triangulations from $\geq$3 bearings taken from fixed stations using 4-element yagi or H-Adcock antennas. We estimated locations and associated error polygons using LOCATEII (Nams 1990). We conducted radiotelemetry during 0500–2100 hours. We did not conduct night radiotelemetry to avoid disturbing study area residents.

Space-Use Analysis

We used human dwellings as a surrogate to human influence on deer because human activity and disturbance are generally greatest near dwellings. We assessed deer space-use relative to dwellings using 2 separate analyses: 1) density of dwellings (dwellings/ha) in home ranges versus core areas and 2) habitat selection relative to dwellings at the home-range and core-area levels.

Home-range and core-area estimation.—During 2003–2005, we estimated home ranges and core areas for the fawning season (15 May–31 Jul) and winter season (15 Dec–15 Mar). We chose these periods because they represent extremes in both plant phenology and deer behavior. For each deer, we attempted to obtain $\geq$50 locations per season (Seaman et al. 1999). Each GPS collar obtained $>$2,000 locations per 5–6-month period (Schauber et al. 2007); thus, a random subsample of 50 locations was used for analysis for GPS-collared deer. We used the Animal Movements extension in Arcview 3.2 to calculate least-squares cross-validated, fixed-kernel home ranges and core areas (95% and 50% contours, respectively; Worton 1989).

We pooled home-range and core-area data across years, and used the mean home-range and core-area size when the same individual had home ranges and core areas in consecutive years. We used paired *t*-tests ($\alpha = 0.05$ throughout) to compare home-range and core-area size between the fawning and winter seasons.

Dwellings in home ranges and core areas.—We calculated density of dwellings (dwellings/ha) within seasonal home ranges and core areas. We used dwelling density rather than the number of dwellings per home range or core area to correct for individual and seasonal differences in home-range and core-area size. For example, a home range with a larger area may be more likely to contain more dwellings than a smaller home range. We used analysis of variance (ANOVA) to test for differences in mean-transformed dwellings per ha between fawning and winter-season home-ranges and core areas. To reduce the effect of between-deer variation in dwelling density, we restricted the ANOVA to deer for which we had data during both seasons. We also included individual deer as a fixed-factor to better account for individual differences. We performed the ANOVA with interactions, which were removed if they lacked statistical significance.

Habitat selection relative to dwellings.—In ArcView 3.3, we placed a 100-m circular buffer around study area dwellings. We deemed these buffers "zones of high human influence." We classified cover types within and outside the zone of human influence separately. For instance, we treated forest cover outside the zone of influence as a separate cover type from forest cover within the zones. Twenty-eight percent of the study area fell within the zone of high human influence.

We calculated the percent composition of cover types for the study area, home ranges, and core areas. We used the MACOMP.SAS code (Ott and Hovey 1997) in SAS (SAS Institute, Inc., Cary, NC) to perform compositional analysis of habitat selection (Aebischer et al. 1993). We assigned unused but available cover types an insignificant nonzero value (0.0001) because the number zero cannot be log transformed. We tested for seasonal habitat selection between the study area and home ranges (second-order selection [Johnson 1980]) and between home ranges and core areas (third-order selection [Johnson 1980]) for both winter and fawning seasons because deer response to dwellings and associated activity may differ between seasons. When habitat use was nonrandom, we ranked habitats in order of preference (Aebischer et al. 1993).

Bingham and Brennan (2004) found that the substitution of arbitrarily small, nonzero values for 0% habitat use-values led to unacceptably high Type I error rates in compositional analysis. We took steps to eliminate or reduce the proportion of 0% use-values by restricting the compositional analysis to 4 cover types that comprised 84% of the study area: forest and grassland cover outside the zone of influence and those 2 cover types within the zone of influence. This eliminated cover types with low availability that were more likely to be unused (Bingham and Brennan 2004) and allowed us to determine space-use relative to dwellings while partially controlling for habitat selection. For example, if deer are disturbed by houses, then the habitats outside the zones of influence should be ranked higher than the same type of habitats within the zones.

Survival Analysis

During 23 October 2002–15 March 2006, we monitored deer for survival ≥ 2 times per week. We used number of transmitter-days (Trent and Rongstad 1974, Heisey and Fuller 1985*a*) to estimate the annual survival rate and rates of cause-specific mortality in program MICROMORT (Heisey and Fuller 1985*b*). We pooled data across years for analysis. We investigated mortalities immediately following detection. We classified mortalities as DVC or hunter-harvest; deer that died from capture myopathy were not included in the analysis. We recorded the exact date of death for all mortalities. We censored GPS-collared individuals from the analysis when their collars dropped off.

RESULTS

We radiocollared 43 female deer (28 GPS, 15 VHF) during the study period. Averages of 48.9 ± 0.5 (SE) and 50.5 ± 1.9 locations per VHF-collared deer were obtained during the fawning and winter seasons, respectively. Time taken to obtain ≥ 3 bearings for locations averaged 15.5 ± 0.3 minutes. Mean error ellipse size averaged 4.0 ± 0.4 ha.

Space-Use Analysis

Home-range and core-area estimation.—Home-range and core-area sizes were not normally distributed ($W = 0.769$, $P < 0.001$; and $W = 0.782$, $P < 0.001$; respectively). Therefore, we attempted several data transformations to improve normality; a Log_{10} transformation was deemed best for both home-range and core-area size ($W = 0.968$, $P = 0.203$; and $W = 0.988$, $P = 0.915$; respectively).

During the fawning season, mean home-range size was 53.0 ± 5.2 ha ($n = 26$, range = 25.2–145.0 ha) and mean core-area size was 8.7 ± 1.8 ha ($n = 26$, range = 2.6–48.9 ha). In winter, home-range size averaged 90.6 ± 9.7 ha ($n = 34$, range = 23.3–275.0) and core-area size averaged 12.4 ± 1.3 ha ($n = 34$, range = 1.1–32.5). Home ranges were larger in winter than during the fawning season ($t_{24} = 3.42$, $P = 0.002$). Core areas were also apparently larger during the winter, with the difference approaching statistical significance ($t_{24} = 2.06$, $P = 0.051$).

Dwellings in home ranges and core areas.—Dwelling density data were nonnormal ($W = 0.764$, $P < 0.001$), but square-root transformation improved normality ($W = 0.912$, $P < 0.001$). Dwelling density in home ranges and core areas during the fawning season averaged 0.13 ± 0.03 dwellings per ha ($n = 26$, median = 0.11, range = 0.00–0.65) and 0.14 ± 0.05 dwellings per ha ($n = 26$, median = 0.00, range

Table 1. Ranking matrices[a] for fawning-season habitat selection of female white-tailed deer relative to dwellings at the second (A) and third (B) levels of selection (Johnson 1980) in an exurban setting near Carbondale, Illinois, USA, 2003–2005.

	FO[b]	GO[c]	FI[d]	GI[e]	Rank
(A) Home-range vs. study-area habitat selection					
FO	.	−	+	+	2
GO	+	.	+++	+++	3
FI	−	−−−	.	−	1
GI	−	−−−	−	.	0
(B) Core-area vs. home-range habitat selection					
FO	.	+++	+	+++	3
GO	−−−	.	+	+	2
FI	−	−	.	+	1
GI	−−−	−	−	.	0

[a] Log-ratio difference values between pairs of habitat types are replaced by their signs in the matrix. A positive sign indicates the habitat type in the row is preferred over the habitat type in the intersecting column. Signs are tripled when log-ratio differences are significantly different from zero ($\alpha = 0.05$). The rank is equal to the sum of the positive values in that row. Larger rank indicates the habitat type in that row is selected over the habitat types with smaller ranks.
[b] FO = forest cover outside the zone of human influence.
[c] GO = grassland cover outside the zone of human influence.
[d] FI = forest cover within the zone of human influence.
[e] GI = grassland cover within the zone of human influence.

Table 2. Ranking matrices[a] for winter-season habitat selection of female white-tailed deer relative to dwellings at the second (A) and third (B) levels of selection (Johnson 1980) in an exurban setting near Carbondale, Illinois, USA, 2003–2005.

	FO[b]	GO[c]	FI[d]	GI[e]	Rank
(A) Home-range vs. study area habitat selection					
FO	.	−	+	+	2
GO	+	.	+	+++	3
FI	−	−	.	−	0
GI	−	−−−	+	.	1
(B) Core-area vs. home-range habitat selection					
FO	.	+++	+++	+++	3
GO	−−−	.	−−−	−	0
FI	−−−	+++	.	+++	2
GI	−−−	+	−−−	.	

[a] Log-ratio difference values between pairs of habitat types are replaced by their signs in the matrix. A positive sign indicates the habitat type in the row is preferred over the habitat type in the intersecting column. Signs are tripled when log-ratio differences are significantly different from zero ($\alpha = 0.05$). The rank is equal to the sum of the positive values in that row. Larger rank indicates the habitat type in that row is selected over the habitat types with smaller ranks.
[b] FO = forest cover outside the zone of human influence.
[c] GO = grassland cover outside the zone of human influence.
[d] FI = forest cover within the zone of human influence.
[e] GI = grassland cover within the zone of human influence.

= 0.00–1.21), respectively. Dwelling density of home ranges in winter averaged 0.18 ± 0.02 dwellings per ha ($n = 34$, median = 0.15, range = 0.00–0.64) and dwelling density in winter core areas was 0.16 ± 0.03 dwellings per ha ($n = 34$, median = 0.12, range = 0.00–0.63). Dwelling densities differed among seasons and home range and core area ($F_{72,23} = 4.598$, $P = 0.033$). Deer used areas of higher dwelling density in the winter than during the fawning season ($P = 0.029$) and dwelling density was higher in home ranges than core areas ($P = 0.010$).

Habitat selection relative to dwellings.—Compositional analysis provided evidence of nonrandom habitat use during the fawning season at both the second ($\lambda = 0.728$, $P = 0.059$) and third levels of selection ($\lambda = 0.716$, $P = 0.078$). During the fawning season, within home ranges, grassland outside the zone of human influence was selected over both grassland and forest within the zone of human influence (Table 1). At the core-area level, forest outside the zone was selected over both grassland cover types (Table 1).

Winter habitat use was nonrandom at both the second ($\lambda = 0.739$, $P = 0.023$) and third levels of selection ($\lambda = 0.641$, $P = 0.003$). At the home range level, grassland outside the zone of human influence was preferred over grassland within the zone of influence (Table 2). There were no detectable differences in habitat selection between other cover types. Within core areas, forest outside the zone of influence was selected over all other cover types. Forest cover within the zone of influence was selected over both grassland cover types (Table 2).

Survival Analysis

We monitored 43 females for survival during 18,655 transmitter-days. No radiocollars failed during the study. The annual survival rate was 0.872 (SE = 0.048). Seven deer died during the study: 3 harvested by shotgun hunters, 2 killed by archery hunters, 1 poached, and 1 killed in a DVC. Cause-specific mortality rates were 0.091 (SE = 0.038) for hunter harvest and 0.018 (SE = 0.057) for both DVCs and poaching.

DISCUSSION

Our results suggest that the human development found in exurbia influences deer space-use. Furthermore, the low harvest rate of deer on our study area suggests that exurban development can substantially hinder the ability of state natural resource agencies to manage deer populations through hunter harvest.

Space-Use Analysis

Home-range and core-area size.—Deer in our exurban study area had larger home ranges than most suburban deer and generally smaller home ranges than rural deer (Table 3). These results can be partially explained by how deer habitat composition and configuration differ across the rural–urban gradient. Development influences deer home-range size by altering habitat composition and productivity and, in suburban areas, by introducing impediments to movement (e.g., highways, railroads, and commercial and residential expanses; Grund and Woolf 2002). The barriers to deer movement that exist in suburban areas are much less prevalent in the exurban landscape. However, exurban development increases forest fragmentation and adds anthropogenic food sources that could facilitate smaller home ranges in exurbia relative to rural areas as deer could decrease movements while still meeting metabolic demands.

Deer in nearby suburban Carbondale, Illinois (Cornicelli

Table 3. Selected home-range sizes of female white-tailed deer with references to human development intensity in the United States, 1985–2005.

Study	State	Home-range estimator	Development level	Home-range size (ha)	
				Summer–fawning	Winter
Tierson et al. (1985)	NY	Hand-drawn	Rural	221	132
Nixon et al. (1991)	IL	Min convex polygon	Rural	55	177
Cornicelli et al. (1996)	IL	Min convex polygon	Suburban	17	37
Filipiak (1998)	MN	Adaptive kernel	Rural	191	436
Kilpatrick and Spohr (2000)	CT	Adaptive kernel	Suburban	33	36
Grund et al. (2002)	MN	Adaptive kernel	Suburban	50	85
Campbell et al. (2004)	WV	Fixed kernel	Rural	79	92
Porter et al. (2004)	NY	Min convex polygon	Suburban	21	22
This study	IL	Fixed kernel	Exurban	53	91

et al. 1996) had much smaller home ranges than deer on our exurban area, even though the 2 study sites were only 5 km apart. That 2 deer populations so close together could have such differences in home-range size further reinforces the notion that deer in the most human-dominated landscapes have smaller home ranges than their counterparts in relatively less-developed areas.

Space-use relative to dwellings.—Deer generally avoided dwellings on our study area, similar to suburban deer (Vogel 1989, Cornicelli et al. 1996, Kilpatrick and Spohr 2000, Grund et al. 2002). This conclusion is based on 2 analyses: 1) dwellings within home ranges and core areas and 2) habitat use relative to dwellings. These analyses were generally concordant and complementary and provide insight into deer ecology in exurban areas.

Fawning season compositional analysis did not achieve statistical significance, which may be explained by the smaller sample size of deer during the fawning season ($n = 26$ in fawning season vs. 34 in winter season). Also, the home ranges of 3 of 26 deer considered for fawning-season analysis contained no habitats within 100 m of a dwelling. This likely biased the third-order selection in a way that would underestimate avoidance of dwellings. Although the fawning-season compositional analysis did not quite achieve statistical significance, considering the ranks obtained from the compositional analysis together with the dwelling density results suggests biological significance. Thus, we will discuss fawning-season results based on the notion that deer were exhibiting biologically meaningful habitat selection.

Deer during the fawning season had a lower dwelling density in their core areas than in home ranges, implying that deer on the study area avoided houses to a degree during this time. That the dwelling density was lower in fawning-season home ranges than both winter home ranges and core areas suggests a stronger avoidance during the fawning season. Deer in suburban Groton, Connecticut, USA, showed no seasonal differences in the number of dwellings per home range; however, there were more houses in winter core areas than in other seasons (Kilpatrick and Spohr 2000). The relatively high level of development in the suburbs probably diminished the ability of deer to exhibit seasonal differences in the number of dwellings per home range, through either home range contraction or shift.

Deer on our study area exhibited a second-order selection, during the fawning season, for grassland away from dwellings over habitats nearer to dwellings. Most of the grassland >100 m from dwellings was either fescue fields or idle lands containing thick ground cover. Such grassland is important habitat in southern Illinois in the summer since fawns are typically hidden along the grassland–forest edge (Rohm et al. 2007) and as adults may use the tall grass for cover as well. Much of the grassland on our study area <100 m from a dwelling was lawn, which does not provide any cover, thereby resulting in deer avoidance. Female deer may also prefer to give birth in relatively quiet areas, away from the noise and disturbances associated with homes (Grund et al. 2002). These reasons also explain why there were fewer dwellings in core areas of deer during the fawning season.

Unlike deer in our exurban study area, suburban deer in Connecticut and Minnesota, USA, increased use of residential areas during winter (Kilpatrick and Spohr 2000, Grund et al. 2002). Swihart et al. (1995) reported that suburban deer in Connecticut browsed more heavily near houses than away, and that deer regularly visited houses when foraging in winter. The shift towards dwellings in winter was explained by the anthropogenic food sources found there and (Swihart et al. 1995), in the case of Grund et al. (2002), the radiant heat and reduced wind speeds provided by homes.

In second-order selection during the winter season, deer selected grassland away from dwellings over grassland close to houses, which may indicate that anthropogenic food sources associated with dwellings are not so important in exurbia, especially given that winters are generally mild in southern Illinois. The only instance in which a habitat type <100 m from a dwelling was selected over a habitat type >100 m from a dwelling occurred at the core-area level, during the winter season. That forest cover <100 m of dwellings was selected over grassland >100 m from dwellings probably means that deer are less apt to avoid dwellings in the winter than during the fawning season.

Survival

Annual survival of deer in our exurban study area (87%) was higher than survival rates reported in both rural areas (57–76%) and suburban areas (62–82%; Table 4). Deer–vehicle collisions are generally the principal cause of mortality in

Table 4. Annual survival rates of adult female white-tailed deer in the Midwestern and Northeastern United States, with respect to intensity of development, 1990–2005.

Study	State	Development level	Annual survival rate (%)
Fuller (1990)	MN	Rural	69
Nixon et al. (1991)	IL	Rural	71
Swihart et al. (1995)	CT	Suburban	82
Deperno et al. (2000)	SD	Rural	57
Beringer et al. (2002)	MO	Suburban	69
Etter et al. (2002)	IL	Suburban	82
Brinkman et al. (2004)	MN	Rural	76
Porter et al. (2004)	NY	Suburban	62
This study	IL	Exurban	87

suburban areas (Etter et al. 2002, Nielsen et al. 2003, Porter et al. 2004), although lethal control methods such as sharpshooting are important where they occur. In our study, DVCs were few because only 3 major roads crossed the study area. Road density (1.5 km/km^2) on our study area was intermediate between typical rural areas and suburban areas; however, most roads on our study area were driveways, which experienced light traffic at low speed.

Hunting is typically the primary cause of death for deer in rural areas (Nixon et al. 1991, Brinkman et al. 2004). On our study area, hunter harvest was low because only 19% of landowners allowed deer hunting on their property (Storm et al. 2007). On 30% of hunted properties, one bow hunter constituted all of the hunting that took place. Exurban development has been demonstrated to reduce efficiency of county-level deer harvest in Illinois (Harden et al. 2005), and this is clearly true on our study area. The extremely low harvest rate of deer in our study area indicates that recreational hunting alone is not likely effective for managing deer in exurbia.

MANAGEMENT IMPLICATIONS

Exurbia will continue to expand, and as it does, the land area over which deer managers may exert some degree of deer population management will decrease. Exurban development creates a landscape in which development is not so intense as to substantially reduce the amount of deer habitat, yet is intense enough to markedly reduce hunting. The likely end result of exurban development is highly abundant deer populations, moderate human populations, and high potential for deer–human conflict (Storm et al. 2007). Given the limits of traditional hunter harvest as a tool for deer management in exurbia, agencies must identify alternative policies and regulations to manage deer. We are uncertain what these alternatives may be; however, we are sure that any solutions that may exist will have to be implemented in the context of increasing human and deer populations and decreasing hunter numbers.

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