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Original Article

Effects of Landscape and Land-Ownership Patterns on Deer Movements in a Suburban Community

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ABSTRACT White-tailed deer (*Odocoileus virginianus*) have adapted to, and are thriving in, residential–suburban landscapes. Special hunts, sharpshooting programs, and fertility control efforts have been implemented in residential communities to reduce local deer populations. For these management strategies to be effective, it is important to understand deer movement and behavior patterns in suburban landscapes. Our objectives were to quantify annual and hunt-season home-range size, and evaluate the relationships between landscape characteristics, land-ownership patterns, and deer movements during the autumn hunting season. Much variation in home range size was observed for annual (15.5–173 ha) and hunt-season home range (16.8–120.7 ha) over the 2-yr study. Deer core areas were not characteristically different from home ranges with regards to forest lands or building density, but were different with regards to road density and property density. Deer use of core areas during the day was similar to, or higher than, deer use at night. Most individual properties in deer core areas were <2.8 ha. Under the current set-back distance for firearms hunting (152 m), 31% and 38% of deer had no portion of their home range potentially open to firearms hunting, and 69% and 81% had no portion of their core areas potentially open to firearms hunting in years 1 and 2. Percentage of forest in home range buffers decreased from 66% in year 1 (abundant acorns) to 46% in year 2 (moderate acorns) as deer shifted into residential development. Findings from our study emphasize the value of conducting multiyear studies and incorporating other variables such as mast abundance to improve interpretation of landscape models. The close association of deer core areas with roads suggests that sharpshooting programs that bait and shoot deer from roads may be an effective management option. In suburban landscapes, deer core areas are comprised of many different landowners, limiting hunter access and mobility to deer core areas. No-hunt buffers around buildings should be reduced to levels that increase hunter access to deer core areas, yet maintain reasonable safety zones.

KEY WORDS home range, hunt season, land-ownership patterns, landscapes, *Odocoileus virginianus*, white-tailed deer.

In suburban landscapes, white-tailed deer (*Odocoileus virginianus*) experience high survival rates and have adapted to living in these human-dominated landscapes (Kilpatrick and Spohr 2000, Etter et al. 2002, Grund et al. 2002). Concerns with overabundant deer populations include: risk of contracting tick-borne diseases, deer damage to landscape plantings, degradation of forest ecosystems, reduced bird species abundance and diversity, and risk of deer–vehicle accidents (Kilpatrick and Walter 1997, McShea and Rappole 2000, Shanahan et al. 2001, Horsley et al. 2003, Kilpatrick and LaBonte 2003). Special hunts (Deblinger et al. 1995, Kilpatrick et al. 1997, Kilpatrick and Walter 1997, Mitchell et al. 1997), sharpshooting programs (Drummond 1995, Stradtmann et al. 1995, Butfiloski et al. 1997, DeNicola et al. 1997, DeNicola and Williams 2008), and fertility control efforts (Rudolph et al. 2000, Walter et al. 2002, Rutberg et al. 2004, Curtis et al. 2008) have been implemented in residential communities to reduce local deer populations. Developing effective management strategies in suburban landscapes is especially challenging because deer vulnerability to hunting may be low (Storm et al. 2007*a*) and survival rates high, due to lack of hazards and avoidance behavior (Etter et al. 2002). Knowledge of deer use of suburban landscapes is important for developing effective management strategies and assessing management programs.

During the past 15 yr, telemetry studies have focused on describing movements and habitat use of deer in suburban landscapes (Kilpatrick and Spohr 2000, Etter et al. 2002, Grund et al. 2002, Porter et al. 2004, Storm et al. 2007*b*). Previous research has shown that deer in suburban landscapes tend to have relatively small home ranges (Henderson et al. 2000, Kilpatrick and Spohr 2000, Etter et al. 2002, Grund et al. 2002, Porter et al. 2004), experience high

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survival rates (Etter et al. 2002, Storm et al. 2007*b*), exhibit strong site fidelity (Grund et al. 2002, Porter et al. 2004), and commonly use residential landscapes for foraging, particularly during winter (Swihart et al. 1995, Kilpatrick and Spohr 2000, Grund et al. 2002).

Correlations between landscape characteristics and home range size have been investigated for mule deer (*O. hemionus*; Kie et al. 2002), elk (*Cervus elaphus*; Anderson et al. 2005), and roe deer (*Capreolus capreolus*; Lamberti et al. 2006, Coulon et al. 2008). Recently, Walter et al. (2009) explored the relationships between landscape configuration and connectivity on annual home-range size of white-tailed deer in a forested–agricultural landscape and exurban development. No studies have evaluated the relationship between landscape characteristic and land-ownership patterns and how these variables affect deer movements in suburban landscapes during the autumn, when most deer management programs are implemented. Our objectives were to quantify annual and hunt-season home-range size, and evaluate the relationships between landscape characteristics, land-ownership patterns, and deer movements in a suburban landscape during the autumn hunting season.

STUDY AREA

The study area was the town of Greenwich, Connecticut, USA, a 124-km^2 township located in Fairfield County in the southwest corner of Connecticut. Greenwich was bounded on the south by Long Island Sound, on the east by the City of Stamford, and on the north and west by Westchester County, New York, USA. The human population was about 58,000 (461 people/km^2; 1998–1999 census data). Greenwich was primarily residential, with 0.81-ha and 1.62-ha minimum zoning restrictions for house lots in the northern two-thirds of town. Greenwich was 36% forest land (hardwoods), 29% turf–nursery, 23% commercial–residential, 8% field–pasture, and 4% other.

Estimated deer population in the town of Greenwich was 2,566 (20.7 deer/km^2; Kilpatrick et al. 2004). Estimated mean annual archery deer harvest was 421 (3.4 deer/km^2; Kilpatrick et al. 2004). From 1998 to 2001, 95% of deer harvested in Greenwich were taken during the archery season (Kilpatrick et al. 2001, 2002). Using the 2002 deer-hunting season framework, each archery hunter in Greenwich could harvest 2 adult male deer and unlimited antlerless deer (no cost for additional antlerless deer tags) in any order during a 91-day archery deer-hunting season (15 Sep–31 Dec). Firearm hunters could harvest 2 deer (one either-sex and one antlerless-only) and unlimited antlerless deer (no cost for additional antlerless deer tags) during the shotgun–rifle season (20 Nov–10 Dec) and 2 more deer during the muzzleloader deer-hunting season (11–24 Dec). Hunting on Sundays or with the use of bait was prohibited. Deer hunters were required to obtain written permission from the landowner to hunt on private land. Firearm hunting was prohibited within 152 m of buildings occupied by people, domestic animals, or used to store flammable materials, unless a written waiver was obtained from the landowner. No minimum distance was required for archery hunting.

METHODS

Deer Capture

We immobilized adult female deer using a dart gun (model 171c; Pneu-Dart, Inc., Williamsport, PA) equipped with a 4× scope, laser sight (Emerging Technologies, Inc., Little Rock, AR) and disposable 2-cm^3, wire-barbed darts (Pneu-Dart, Inc.) equipped with radiotransmitters (Advanced Telemetry Systems, Isanti, MN). Darts contained 280 mg of Telazol and 225 mg of xylazine hydrochloride. We captured deer at bait sites from January to April in both 2002 and 2003 and equipped them with radiocollars (Advanced Telemetry Systems, Inc.; model 9c.) and ear tags. We aged deer by tooth wear and replacement method (Severinghaus 1949) before administering a 6-mg intravenous injection of yohimbine hydrochloride, a reversal agent for the xylazine hydrochloride. We established multiple bait sites for capturing deer in Greenwich that had various levels of development. We placed whole-kernel corn at baits located in forest openings and residential areas. We darted deer from elevated platforms, stationary vehicles, or buildings. At night, we used a 1,000,000-candlepower spotlight to aid in seeing and darting deer at bait sites. Personnel trained by a wildlife veterinarian in humane capture and chemical restraint methods conducted this project. The University of Connecticut Animal Care Committee reviewed and approved capture and handling procedures (Institutional Animal Care and Use Committee no. B370 0401).

Radiotelemetry

We recorded deer locations twice weekly using a hand-held 3-element Yagi antenna and portable receiver (Telonics, Inc., Mesa, AZ; model TR-2). Deer locations were triangulated (intersecting angles between 60° and 120°) once during a 12-hr day and once during a 12-hr night period each week. We plotted telemetry bearings and locations on 7.5-min United States Geological Survey topographic maps. We measured angular telemetry error as the median difference between true and estimated bearings to 6 test transmitters in 1 blind test.

We digitized deer locations using Program TRIANG (White and Garrott 1984) using the Universal Transverse Mercator coordinate system for reference (Grubb and Eakie 1988). We used the adaptive kernel method in RANGES V (Kenward and Hodder 1996) to estimate deer home ranges and core areas, which may overestimate home ranges, compared to the fixed-kernel method (Kernohan et al. 2001). To minimize the effects of telemetry error on home range estimates, we removed locations with relatively large error polygons (>10% of mean home-range size; White and Garrott 1990). We tested home-range data for normality using the Shapiro–Wilks normality test at the 0.05 significance level. We transformed nonnormal data using the natural log. We calculated deer home-range size using a cell size of 40 × 40 and the 95% probability distribution to minimize effects of outliers. We delineated core area size using the 50% probability distribution. The computer generated an optimum bandwidth to delineate home ranges using the least-squares cross-validation score. We estimated annual and hunt-season (15 Sep–31 Dec) home ranges. We determined the minimum number of telemetry locations required per deer to compute home range size that was independent of sampling intensity using an area-observation curve (Odum and Kuenzler 1995).

Landscape Data

We obtained a digital geo-referenced aerial photograph (1997) at a 0.3-m-pixel resolution and a 2001 geographic information system database (property boundaries, buildings, roads, driveways and parking lots, water bodies) from the town of Greenwich Information Technology Department. We error-checked these data layers against the aerial photograph. We digitized land cover into 6 categories: forest, grass, developed, shrub, barren–gravel, and water bodies. Forest included all forested patches ($\geq$0.2 ha) with overstory cover. Grass included fields, meadows, athletic fields, parks, golf courses, and cemeteries. Developed included all buildings, maintained yards, driveways, parking lots, roads, pools, and tennis courts. Shrub included shrub areas with no overstory. Barren–gravel included nonvegetated areas. Water bodies included all ponds, lakes, and flowages that were $\geq$1.5 m wide. We converted land-cover polygons to raster layers using a 4-m-pixel resolution using ArcMap 9.2 (Environmental Systems Research Institute, Inc., Redlands, CA).

We overlaid autumn home ranges and core areas of deer on geo-referenced aerial photographs using ArcMap 9.2. We used the median distance deer were located outside their autumn home range, but within their 100% area use, to delineate buffers around home ranges. Within deer core areas, home ranges, and home range buffers, we extracted landscape and anthropogenic metrics using ArcMap. We generated landscape metrics using FRAGSTATS 3.3 (McGarigal et al. 2002), and metrics that were presumably biologically meaningful were selected for analysis (Table 1). In addition to percent developed land generated from FRAGSTATS, other anthropogenic metrics generated from ArcMap included building density (buildings/ha), road density (m/km^2), and property density (no./ha).

We delineated a 152-m buffer around all houses to denote the legal minimum distance from a house required to hunt with firearms in Connecticut. We deleted buildings $\leq$49 m^2 from the data set to exclude sheds, pool houses, camp shelters, cemetery structures, and other outbuildings. We calculated percentage of deer home range and core area outside the 152-m buffer that was potentially available to firearms hunting. We repeated this measurement using a reduced buffer of 122 m and 91 m to assess changes in hunter access to deer with firearms, if the minimum distance was reduced. We counted number of individual properties that comprised each deer's home range and core area to evaluate potential difficulties for hunters in obtaining written permission from multiple property owners to access deer.

Statistics

We conducted all statistical analyses using SYSTAT 12.0 (SYSTAT Software 2007). We tested landscape-level data for normality using Shapiro–Wilks normality test ($P < 0.050$) and nonnormal data were transformed using the natural log or arcsine for proportion data. We used nonparametric statistics to analyze data that could not meet the assumptions of normality. We compared home range size for deer with 2 yr of data between years using a paired-sample t-test ($P < 0.050$). If home range size did not differ between years and spatial overlap between years was high (>80%), than all locations were pooled between years to calculate landscape metrics. We compared home range size of 25 deer that survived 1 yr using 10 months and 12 months of movement data. Differences in home range size between a partial (10 months) and complete (12 months) data set were examined using a paired-sample t-test ($P < 0.050$). If no differences in size existed, and home range overlap was high (>80%), then deer that survived $\geq$10 of 12 months were used for estimating annual home ranges. We determined the minimum number of telemetry locations per deer needed to conduct home range analysis by analyzing area–observation curves (Odum and Kuenzler 1995) of 10 deer. We evaluated differences in potential access for firearms hunting using the current no-firearms discharge buffer (152 m), and 2 reduced buffers (122 m and 91 m), using Quade Multiple-Comparison test ($P < 0.050$). We compared differences in deer use of core areas during the day and at night using the Wilcoxon matched-pairs test ($P < 0.050$). We evaluated differences in landscape metrics among core areas, home ranges, and buffers for each deer using analysis of variance (ANOVA) repeated measures and the Bonferroni post hoc pair-wise comparison ($P < 0.050$). We tested deer with overlapping core areas for independence using the coefficient of association (Cole 1949; $P < 0.050$). If 2 deer possessed a significant coefficient of association, then 1 deer was randomly selected and removed to address the assumption of independence.

Table 1. Metrics generated from Program FRAGSTATS (McGarigal et al. 2002) to assess spatial structure and composition of landscapes used by white-tailed deer in Greenwich, Connecticut, USA, 2002–2004.

Metrics	Description
Class metrics	
For%	% Forest land
ForPD	Patch density of forest land (no./ha)
ForED	Edge density of forest land (m/ha)
Dev%	% Developed land
DevPD	Patch density of developed land (no./ha)
DevED	Edge density of developed land (m/ha)
Landscape metrics	
LandPD	Patch density (no./ha)
LandED	Edge density (m/ha)
Shape	Shape index (irregularity of patch shape)
IJI	Interspersion/juxtaposition
Contagion	Contagion index (clumpiness)
SIDI	Simpsons diversity index

Landscape Effects on Deer Movements

We developed least-squares regression models to assess the effects of landscape characteristics on home range size during the autumn hunting season. We used Pearson's correlation coefficient (r) to select predictor variables that were correlated ($r \geq 0.4$) to the response variable, but not correlated

($r < 0.4$) to other predictor variables. Based on this criterion, we generated multiple models using all possible combinations of uncorrelated predictor variables. We assessed model fit using R^2, which indicates how much variation in the model is attributed to the predictor variables. Other parameters included to aid in model interpretation included Akaike Information Criteria (AIC), and the P-value in the ANOVA. The AIC score can be interpreted as an estimate of the relative discrepancy between the model and the unknown true model that generated the data; a low AIC score is preferred (Burnham and Anderson 2002). The R^2 criterion tends to bias toward models with more parameters and the AIC criterion tends to bias toward the most parsimonious model (Burnham and Anderson 2002). The P-value from the ANOVA indicates whether the predictor variables have a significant effect on the response variable. We used the difference in AIC (ΔAIC) and Akaike weights to compare the relative performance of the models (Burnham and Anderson 2002). ΔAIC is a measure of each model relative to the best model. Models having a $\Delta\text{AIC} < 2$ have substantial support as a competing model, those in which $3 < \Delta\text{AIC} < 7$ have considerably less support, and models having $\Delta\text{AIC} > 10$ are unlikely, competing models (Burnham and Anderson 2002). Akaike weights provide another measure of strength of evidence for each model and represent the ratio of ΔAIC for each model relative to the whole set of candidate models (Burnham and Anderson 2002). We evaluated the predictive performance of the selected model by running a k-fold cross-validation on our data sets. Similar to Ng et al. (2008), we randomly divided the data into 5-fold; 4-fold (80%) for model training and 1-fold (20%) for model testing. Cross-validation was repeated 5 times, with a different fold of data withheld each time for validation data. We calculated the mean squared error for all 5 test models as an indicator of model performance.

RESULTS

Deer Movements

A total of 7,376 data points was collected from 56 deer over a 2-yr period. Seven hundred thirty-two telemetry locations were $\geq$10% (9.8 ha) of preliminary home-range estimates and were deleted from the data set. The minimum number of data points required to estimate home range size was 44 for annual and 28 for hunt-season home ranges. No difference existed in mean home-range size between deer using 10 months and 12 months of data ($t_{24} = 0.236$, $P = 0.815$) and mean overlap between groups was 93%.

Annual home ranges were estimated using 41 of 56 deer that survived $\geq$10 of 12 months and had $\geq$44 data points collected. Mean annual home-range size of 25 deer that survived 2 yr was significantly different between years ($t_{24} = 4.904$, $P < 0.001$) and, therefore, data were not pooled between years. Mean annual home ranges and core areas were estimated for 37 deer in year 1 and 29 deer in year 2 (Table 2). Deer that survived the hunting season (Sep–Dec) and had $\geq$28 data points collected were used to estimate home range size during the regulated deer-hunting seasons. Mean hunt-season home ranges and core areas were estimated for 21 deer in year 1 and 14 deer in year 2 (Table 2).

Landscape Analysis

Three deer were removed from analysis in year 1 ($n = 21$) due to a significant coefficient of association. Building density in year 1 was higher in the home range buffer than in the home range ($F = 3.240$, $P = 0.050$), but building density in the core area was similar to the home range ($P = 1.000$) and the home range buffer ($P = 0.180$). Building density in year 2 was similar among the core area, home range, and home range buffer ($F = 0.290$, $P = 0.750$). Percent forest land among the core area, home range, and home range buffer was similar in year 1 ($F = 1.096$, $P = 0.343$) and year 2 ($F = 0.147$, $P = 0.864$). Road density was higher in core areas than in home ranges ($F = 9.217$, $P = 0.018$) and buffers ($P < 0.001$) in year 1. Road density exhibited the same pattern in year 2, except differences were not significant ($F = 1.219$, $P = 0.307$).

Deer used core areas more often during the day, compared to night, in year 1 ($P = 0.004$) and use was similar between day and night during year 2 ($P = 0.778$). Mean number of properties that comprised deer core areas was similar during both years (Table 3). Size of individual properties in deer core areas ranged from 0.4 ha to 2.8 ha, and averaged 1.2 ha. Mean property density (no./ha) was higher in core areas compared to home ranges in year 1 (1.1 vs. 1.5; $t_{12} = 2.205$, $P = 0.019$) and year 2 (1.3 vs. 2.1; $t_{20} = 2.091$, $P = 0.050$). Using a 152-m no-hunt buffer around all buildings, median percentage of deer core area and home range potentially accessible to firearms hunting was 0% and $\leq$1.4% during both years. Percentage of deer home range and core areas not included in the no-hunt buffer increased as the buffer was reduced for both years (Table 4).

Landscape Effects on Deer Movements

The landscape analysis was performed using a 134-m buffer around deer home ranges during the autumn hunting season. Four of 12 predictor variables in the landscape analysis

Table 2. Annual and autumn hunt-season home range (ha) and core area size (ha) for female white-tailed deer in Greenwich, Connecticut, USA, 2002–2004.

		No. of locations		Home ranges			Core area		
Time period	Deer (n)	Mean	SE	Mean	SD	Range	Mean	SD	Range
Annual—Yr 1	37	81	1.4	78.9	24.7	26.1–173.1	20.6	10.2	5.9–61.8
Annual—Yr 2	29	77	2.6	60.7	30.4	15.5–143.8	16.7	8.8	3.1–40.9
Autumn—Yr 1	21	32	0.7	56.1	22.5	21.6–120.7	13.4	7.8	3.4–33.1
Autumn—Yr 2	14	29	0.3	48.9	23.3	16.8–98.4	13.5	7.2	4.8–32.4

Table 3. Number of properties and percentage of white-tailed deer locations in core areas in Greenwich, Connecticut, USA during 2002 ($n = 20$) and 2003 ($n = 13$).

	Core areas					
	No. of properties		Day locations		Night locations	
Statistics	Yr 1	Yr 2	Yr 1	Yr 2	Yr 1	Yr 2
Min.	6	7	37.5	47.1	0.0	30.8
Max.	38	31	77.3	76.5	63.6	75.0
Mean	17.6	17.2	61.8	59.1	42.3	58.6
SE	1.8	2.0	2.3	2.0	3.3	3.8

Table 4. Median percentage of white-tailed deer home ranges and core areas potentially available for firearms hunting, using 3 distance buffers around buildings, Greenwich, Connecticut, USA, 2002–2004. When comparing percent of land in the home range, core areas were excluded.

	Home-range buffer distance				Core-area buffer distance			
Time period	152 m	122 m	91 m	Quade test *P*-value	152 m	122 m	91 m	Quade test *P*-value
Yr 1	1.4	6.2	17.3	<0.001	0	0.7	8.2	≤ 0.001
Yr 2	0.1	0.2[ns]	2.8	≤ 0.013	0	10.4	28.2	<0.001

[ns] Differences were not significant between 152-m and 122-m buffers.

were correlated ($r \geq 0.4$) to home range size during both years. Autumn home-range size in year 1 was inversely correlated with patch density ($P = 0.055$) and road density ($P = 0.055$), but not correlated to forest edge ($P = 0.12$) or patch density of forest lands ($P = 0.115$). Hunt-season home-range size in year 2 was positively correlated with percentage of developed land ($P = 0.009$) and road density ($P = 0.025$), but not correlated to patch density of developed lands ($P = 0.130$) or building density ($P = 0.161$). To build all possible variable-combination models, each of the 4 predictor variables was used in all possible combinations with the 3 remaining predictor variables, if variables were uncorrelated ($r < 0.4$). A regression analysis was performed on each model's main effects and interaction effects, totaling 11 candidate models (Table 5). Four models had $R^2 > 0.4$ and had significant *P*-values (models 1, 2, 7, 8). Based on the ΔAIC, there were 2 competing models in year 1 (models 1 and 2) and Akaike weights provided stronger evidence for model 1 as the best model. Based on the ΔAIC, only 1 competing model existed in year 2 (model 7) and evidence was further supported by the relatively high Akaike weight. The mean squared error (MSE_{5fold}) was 0.107 for model 1 and 0.141 for model 7 (Table 6).

DISCUSSION

Home Range Size

Much variation in home range size was observed for annual (15.5–173 ha) and hunt-season home range (16.8–120.7 ha) over the 2-yr study. On average, core areas occupied about a quarter of the annual and hunt-season home range. Annual home-range size was similar to other studies conducted in developed landscapes (urban, suburban, exurban), ranging from 43 ha to 158 ha (Kilpatrick and Spohr 2000, Etter et al. 2002, Grund et al. 2002, Storm et al. 2007*b*, Walter et al. 2009). Hunt-season home-range size was similar to other studies conducted during the autumn period in developed landscapes, ranging from 32 ha to 93 ha. Home ranges in

Table 5. Candidate models for comparing the effects of landscape patterns on white-tailed deer home-range size (Hrsize) in Greenwich, Connecticut, USA, 2002–2004.

	ANOVA				
Model no. and variables[a]	R^2	*P*-value	AIC	ΔAIC	Akaike wt
Yr 1					
1—Hrsize = LandPD + RdDEN	0.457	0.019	14.5	0.0	0.416
2—Hrsize = LandPD + RdDEN + LandPD × RdDEN	0.517	0.028	14.7	0.2	0.376
3—Hrsize = ForPD + RdDEN	0.340	0.067	17.7	3.2	0.084
4—Hrsize = ForED + RdDEN	0.301	0.097	18.6	4.1	0.054
5—Hrsize = ForED + RdDEN + ForED × RdDEN	0.350	0.147	19.4	4.9	0.036
6—Hrsize = ForPD + RdDEN + ForPD × RdDEN	0.347	0.151	19.5	5.0	0.034
Yr 2					
7—Hrsize = Dev%	0.474	0.009	15.0	0.0	0.67
8—Hrsize = DevPD + RdDEN	0.458	0.047	17.4	2.4	0.20
9—Hrsize = DevPD + RdDEN + DevPD × RdDEN	0.460	0.120	19.3	4.3	0.08
10—Hrsize = DevPD + BldDEN	0.296	0.173	20.8	5.8	0.04
11—Hrsize = DevPD + BldDEN + DevPD	0.296	0.345	22.8	7.8	0.01

[a] ForEd, edge density of forest lands; LandPD, patch density of all habitat types; RdDEN, road density; ForPD, patch density of forest lands; Dev%, percent of developed lands; DevPD, patch density of developed lands; BldDEN, building density.

Table 6. Coefficients, standard errors, and mean squared error (MSE_{5fold}) of selected models for predicting the effects of landscape patterns on white-tailed deer home-range size in Greenwich, Connecticut, USA, 2002–2004.

Model	Variables[a]	Coeff.	SE	MSE_{5fold}
1	Constant	4.939	0.343	0.107
	LandPD	−2.205	0.961	
	Rd DEN	−0.310	0.136	
7	Constant	2.951	0.270	0.141
	Dev%	2.070	0.657	

[a] LandPD, patch density of all habitat types; RdDEN, road density; Dev%, percent of developed lands.

developed landscapes tend to be smaller than in forested (171–181 ha; Sweeney 1970, Nelson and Mech 1981, Humphreys and Nelson 1999) and agricultural landscapes (161–170 ha; Nixon et al. 1991, Storm et al. 1995, VerCauteren and Hygnstrom 1998).

Core Area Use

Core areas used by deer during the hunting season were not characteristically different from home ranges with regards to percent forest lands or building density. However, road density and property density was higher in core areas compared to home ranges, suggesting that deer core areas are located in fragmented forest lands rather than large blocks of forest during the hunting season. Core areas averaged about 13 ha during the hunting season. Deer use of core areas during the day was similar to, or higher than, deer use at night. If deer spend most of their diurnal activity in these relatively small areas, then hunter ability to access deer core areas will influence hunter effectiveness and ability to manage deer populations. Between 6 and 38 individual properties comprised deer core areas and most properties were $\leq$2.8 ha. This demonstrates the difficulty of managing deer in developed landscapes, where hunters may gain access to land for hunting, but may only gain access to a small portion of deer core areas. Under the best case scenario, complete access to a deer core area would require permission from 6 landowners. Storm et al. (2007*a*) found that only 19% of landowners in an exurban landscape allowed hunting on their property. Under these conditions of limited access to small properties, use of bait for hunting would increase hunter effectiveness (Kilpatrick et al. 2010). Understanding deer use and characteristics of core areas, and knowledge of land-ownership patterns in core areas, are important in developing effective hunt strategies.

No-Hunt Buffer

In Connecticut, no minimum distance is required when hunting with bow and arrow. Hunting with firearms within 152 m of a building occupied by people or domestic animals, or used for storage of flammable materials is prohibited, unless the homeowner signs a written waiver. A 152-m no-hunt buffer creates a 7.3-ha no-hunt zone around all occupied houses. In developed communities, no-hunt zones around houses can restrict the types of hunting permitted (Storm et al. 2007*a*) and provide refugia for deer. In Illinois, USA, a state regulation prohibiting shotgun hunting within 274 m of inhabited structures would prevent hunting on 30.7% of the total land area for 98 counties studied (Harden et al. 2005). In our study, under the current restriction of 152 m, about a third of the deer had no portion of their home range potentially open to firearms hunting, and most had no portion of their core areas potentially open to firearms hunting.

Under a reduced restriction of 91 m (2.6-ha no-hunt zone), all deer had some portion of their home range potentially open to firearms hunting, and less than a third had no portion of their core areas potentially open to firearms hunting. Although a major portion of deer home ranges remained closed to firearms hunting with the reduced restriction, the reduced no-hunt buffer provided hunter access with firearms to all deer home ranges and most deer core areas. Excessive hunting pressure could cause deer to shift core areas within their home ranges to avoid hunting activity (Kilpatrick and Lima 1999). However, use of bait would have the opposite effect and would shift core areas closer to bait sites, increasing deer vulnerability to hunting mortality (Kilpatrick and Stober 2002). In Connecticut, 28 deer-hunting related incidents involving people and firearms were reported between 1982 and 2009 (Connecticut Department of Environmental Protection, unpublished data). Distance was recorded for 27 of 28 incidents and all distances were $<$91 m.

With no minimum distance required for archery hunting, all portions of home ranges and core areas would be potentially accessible to archery hunting. In developed communities such as Greenwich, unless the current firearms restriction is reduced, future modifications in hunting seasons to increase deer harvest rates will need to focus on the archery season only.

Landscape Effects on Deer Movements

Past studies that evaluated deer movements relative to landscape patterns measured landscape metrics based on a circular buffer around deer home-range centroids (Kie et al. 2002, Anderson et al. 2005), or measured metrics within deer home-range boundaries only (Said and Servanty 2005, Walter et al. 2009). In this study, buffers were unique and reflected individual size and configuration of each deer home range. The buffer accounted for factors just beyond deer home ranges that may influence home range size and configuration, and takes into consideration that deer are occasionally located outside their estimated home range.

Only one predictor variable (road density) was significantly related to hunt-season home-range size during both years. In year 1, road density was inversely related to home range size and 2 of 3 remaining correlated predictor variables were associated with forest lands (edge density and patch density of forest lands). In year 2, road density was positively related to home range size and the 3 remaining correlated predictor variables were related to developed lands (percent developed land, patch density of developed lands, building density). Forest lands appeared to be a more important landscape component in year 1 and developed lands appeared to be a more important landscape component in year 2. In the deer management zone that included the town of Greenwich, the autumn acorn crop was abundant in year 1 and moderate in year 2 (LaBonte et al. 2006). Deer appeared to spend more time in residential areas when acorns were less abundant in the forest, and conversely, spent more time in forested areas when acorns were more abundant.

Of 8 deer that were monitored during the hunt-season for both years, percentage of forest in their buffered home range decreased from 66% in year 1 (abundant acorns) to 46% in year 2 (moderate acorns) as deer shifted into residential development. The contagion index (measure of clumpiness or aggregation of habitat types) was higher in year 1 (63.1) than in year 2 (58.4) when deer ranges included more forest lands. Size of hunt-season home ranges for these 8 deer also decreased from 67.9 ha in year 1 to 36.6 ha in year 2. Reduced home ranges associated with developed landscapes are consistent with other studies (Henderson et al. 2000, Kilpatrick and Spohr 2000, Etter et al. 2002, Grund et al. 2002, Porter et al. 2004). Grund et al. (2002) also observed a shift in deer ranges from park woodlands to residential woodlands during a severe winter. Findings from this study and Grund et al. (2002) emphasize the value of conducting multiyear studies and suggest that incorporating other variables such as mast abundance and weather conditions may improve interpretation of landscape models.

In year 1, the model containing both patch density of the landscape and road density accounted for almost half of all the variation in deer home ranges. In year 2, almost half of all the variation in deer home ranges was accounted for by one variable (percent of developed land). Percentage of developed land had no influence on deer home ranges in year 1, but was the most influential variable in year 2.

MANAGEMENT IMPLICATIONS

Deer core areas were commonly located in forested areas fragmented by roads. In developed landscapes, forested areas near roads need to be accounted for when designing hunt programs. The close association of deer core areas with roads suggests that sharpshooting programs that bait and shoot from roads may be an effective management option.

Hunter access to deer home ranges, and especially deer core areas, is needed to manage deer populations using various methods of hunting. In developed landscapes, deer core areas are comprised of many different land-ownerships, which make it difficult for hunters to access a significant portion of deer core areas. In addition, if access is obtained, it will likely provide limited hunter mobility, due to the relatively small size of individual properties. For hunting to be effective under these conditions, options such as unlimited harvest of deer, use of bait, and use of crossbows likely will be needed.

In developed landscapes, no-hunt buffers around buildings should be reduced to levels that increase hunter access to deer core areas, yet still maintain reasonable safety zones. Developed landscapes with large no-hunt buffers around buildings likely are very dependent on archery hunting only. If large no-hunt buffers exist, changes in the hunting season framework should focus on liberalizations of the archery season.

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