



Original Article

Land Parcelization and Deer Population Densities in a Rural County of Virginia

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ABSTRACT The parcelization of exurban landscapes creates a matrix of intermediately sized and privately managed land parcels, presenting a unique challenge to wildlife managers. During 2010–2011, we studied the correlates between land parcelization, deer density, and hunting patterns in exurban northwestern Virginia, USA. We estimated October deer densities (no. deer/km²) and conducted landowner surveys of deer harvest in 13 study blocks of mean size 34.8 km². The extent of parcelization varied between study blocks; mean parcel size ranged from 2.00 ha to 26.12 ha. We used distance-sampling techniques to survey pre-harvest deer densities in each section, with estimated densities ranging from 9.4 deer/km² to 30.1 deer/km². We quantified deer harvest through calculations of harvest density and the percentage of land hunted. As parcel size increased, the percentage of land hunted increased. Harvest densities reported by landowners, however, remained constant with the exception of 2.0–4.0-ha parcels, which had higher harvest densities than 60.8–161.8-ha parcels. We used linear regression analysis to model the response of deer density (natural log) to landscape metrics, and the best-fit model predicted deer density from mean parcel size with equivalent models including habitat with mean parcel size. Our results suggest that development processes that subdivide rural lands can significantly increase deer populations. The mechanism for this increase may be restricted hunter access to smaller property parcels and/or increased probability of deer refuges nearby. © 2013 The Wildlife Society.

KEY WORDS density estimation, human–wildlife conflict, modeling, *Odocoileus virginianus*, parcelization, population management, Virginia, white-tailed deer.

In recent decades, management of white-tailed deer (*Odocoileus virginianus*) populations in Virginia, USA, and throughout the eastern United States has shifted from population restoration to stabilization and reduction (Foster et al. 1997, Virginia Department of Game and Inland Fisheries 2007). High-density deer populations inflict significant economic damage to agricultural crops, landscaped gardens, and through vehicle collisions (Conover 1984, West and Parkhurst 2002, VerCauteren et al. 2006, McShea et al. 2008) in addition to causing ecological damage to forest species composition and regeneration (Alverson et al. 1988, Stromayer and Warren 1997, Warren 2011, McShea 2012).

Forage limits, predation, hunter harvest, and severe winter conditions are the principal mechanisms that reduce ungulate population size (Patterson and Power 2002, Robinson et al. 2002), with regulated hunting being the primary method used by wildlife managers to keep deer density at “cultural carrying capacity”—the number of deer that can compatibly coexist with human populations (Knox 1997, Brown et al. 2000). Deer overabundance can be defined in ecological and economic terms (Warren 2011). In areas of swelling subur-

ban and exurban development, deer density is a concern due to the prevalence of deer–vehicle collisions and deer-inflicted landscape damage (DeNicola et al. 2000, Storm et al. 2007a, McShea et al. 2008). The transition from rural to exurban or suburban development is coupled by increased parcelization (i.e., the division of large land blocks under single ownership into small blocks under multiple owners), and the resulting fragmented landownership adds further complexity to wildlife management (Harden et al. 2005).

In designing wildlife management solutions, the impacts of exurban development and land parcelization on deer population structure and hunting efficacy must be considered (Vogel 1989, Foster et al. 1997, Lopez et al. 2004, Harden et al. 2005). Forest fragmentation intensifies with human development, producing a patchwork of different vegetation types across a landscape (Saunders et al. 1991, Theobald et al. 1997, Brooks 2003). Initial fragmentation alters the ratio between cover and forage habitat, creating additional edge and increasing the carrying capacity for deer populations (Alverson et al. 1988, Roseberry and Woolf 1998). Studies in both Montana (Vogel 1989) and Florida (Lopez et al. 2004), USA, indicate that the highest deer densities are found at intermediate housing levels where there is increased edge habitat and decreased hunting pressure (Foster et al. 1997, Harden et al. 2005). Land ownership patterns may

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also impact deer populations by indirectly restricting hunter ability to traverse property boundaries.

Our objective was to examine the correlates between parcelization of rural properties, deer population size, and hunting patterns at a local scale. We expected that increased subdivision of land ownership would be associated with increased deer density and decreased harvest density.

STUDY AREA

We selected 11 similar-sized study blocks in Frederick County, a rural northwestern Virginia county targeted for enhanced deer control due to a positive outbreak of chronic wasting disease (CWD). This study was part of a larger effort to monitor deer population density in a region of Virginia where wildlife management focused on reducing the deer population and combating the spread of CWD. We also selected 2 study blocks in a nearby county (Rappahannock County) with similar habitat characteristics and housing densities. Major roads and county borders delineated the 13 study blocks of mean size 34.8 km² that had intermediate levels of forest cover (59–91%), housing density (3.5–18.8 houses/km²), and road density (0.7–2.23 km/km²) and were indicative of the overall forest, house, and road presence in western Frederick County. The dominant land-cover types were forest and field, comprising an average of 72.5% and 18.6%, respectively, of the total land cover in each study block. The mean July high temperature in the region was 30.0° C, the mean January low temperature was –3.3° C, and the average annual precipitation was moderate (108.5 cm; Hayden and Michaels 2000). The majority of land was privately owned (>96%), with one federal property (George Washington National Forest) and no state-owned lands.

METHODS

Hunting Data

We identified all landowners in each study block using the county tax map records, and willing landowners completed a brief survey between September 2010 and February 2011. The Smithsonian Institutional Review Board for Human Subjects Research approved the survey methods (human subjects protocol no. HS11020). The survey comprised 10 questions. Three questions regarded 2009 deer harvest on family-owned property (Did you or anyone else hunt deer on this property in 2009? If yes, how many deer were removed from this property in 2009? How many deer were taken with bow? Muzzleloader? Rifle?). The remaining questions inquired about landowner knowledge of CWD. Landowners were approached directly (i.e., door-to-door, deer check stations, voting polls, public forums), as well as through telephone calls and direct mailings. Landowners were given until February 2011 to return mailed surveys. We surveyed property renters or farm managers when they were more familiar than the landowner with hunting patterns. Survey teams did not concentrate on the deer hunting community, because 98% of interviews were obtained through efforts that

did not single out hunters (voting polls, door-to-door, mailings, and telephone calls).

All adjacent property parcels under the same ownership were merged and treated as a single, larger parcel. Landowners with non-adjacent parcels provided independent data for each property. If a landowner did not have harvest information on each non-adjacent parcel, we allocated harvest to each parcel based on its percent of the total area (<1% of parcels).

In each study block, we split surveyed properties between 7 groups defined by parcel size (in ha): <2.0 (5 acres), 2.0–4.0 (5–10 acres), 4.1–8.0 (10–20 acres), 8.1–20.2 (20–50 acres), 20.3–60.7 (50–150 acres), 60.8–161.8 (150–400 acres), and >161.8 ha. The group cut-offs were based on acres because county and state administrators, when handling land-use matters, use that metric. The range of parcel sizes within each category was determined from visual examination of the data, and we strove to create a relatively equal number of properties in each category. Survey data were pooled by study block and parcel size. Within all 13 study blocks, we calculated the percentage of land hunted and harvest density (i.e., average no. deer harvested/km²) on all the surveyed land in each size class. We also calculated the percentage of land hunted and harvest density for the surveyed land in the individual study blocks. We ran an analysis of variance with a Bonferroni correction to determine the relationships between parcel size, harvest density, and the percentage of land hunted. All statistical analysis was performed using R for Mac OS X (The R Foundation, Vienna, Austria; <http://www.R-project.org>) with a significance level defined by $P < 0.05$.

We used ArcGIS 9.3 to map the occurrence of hunting across surveyed land parcels. County officials in both Frederick and Rappahannock counties provided digitized maps of all property parcels in the study sections. Land parcels were coded as hunted, not hunted, or no data. We laid a grid of 0.25-km² cells over each study block, determined the total number of grid cells comprising each section, and counted the number of grid cells containing land that was not hunted. Within each study block, we calculated the likelihood of a given grid cell containing land that was not hunted. We ran a linear regression to explore the relationship between the mean parcel size of each study block and the likelihood of cells containing land with no hunting (i.e., a deer refuge). We considered this measure to be an index of refuge distribution because we did not have deer harvest data for all parcels within each study block despite our extensive survey coverage (approx. 50% of each study block).

Deer Population Density

We estimated deer densities in the 13 study blocks through spotlighting protocols, a common method used to measure deer population size (McShea et al. 2008, 2011; Hubbard and Nielsen 2011). Density counts were adjusted using distance-sampling techniques to correct for the majority of error associated with spotlighting (Buckland et al. 2001, Focardi et al. 2001, Collier et al. 2007). Spotlighting from public roads onto private property is only legal in Virginia

with landowner permission, which we obtained during the survey effort. State and local law enforcement officials were notified prior to spotlighting.

Prior to firearm hunting season, we surveyed for 8 nights between 19 October and 28 October 2010 from 2030 hours until 0200 hours. We did not conduct surveys on nights with steady rain, excessive wind (>6.6 m/s) or extensive fog. Surveys were conducted from pick-up trucks, each manned by a driver, a data recorder, and 2 observers who shone 3-million candlepower Brinkmann (The Brinkmann Corporation, Dallas, TX) spotlights from the truck's bed while traveling at <2.2 m/s on predetermined public roads. All public roads within a study block were surveyed except those with >2 lanes and speed limits >80 km/hour. Observers simultaneously rotated one spotlight between 0° (directly in front of the truck) and 90° , while the other was rotated between 0° and 270° . Once a deer was sighted, we stopped the truck and determined the group size, distance, and sighting angle to the location where the deer was initially spotted. We measured distances with laser rangefinders and determined angles with handheld compasses. We recorded a group of deer (i.e., deer at rest within 6 m of one another, deer grazing within 6 m of one another, or deer in motion traveling the same direction and within 6 m of one another [LaGory 1986]) as a single sighting. We drove stretches of public road within a single study block that could be continuously spotlighted (i.e., transects) only once each night. Transects ranged in length from 2 km to 15 km. We surveyed transects 2–4 times until we recorded >40 deer sightings in each study block. Thomas et al. (2010) recommend using a sample size of >60 sightings; however, the logistical problems imposed by spotlighting across a matrix of private property forced us to accept a smaller number of sightings.

Land use along transects was a matrix of open and forested land. When transects were pooled by study section, the percentage of open land bordering transects ranged from 23% to 81%. Although there was variability in land cover, we surveyed after leaf fall to minimize the differences between sighting distances in different habitat types. Road density also varied between survey blocks, potentially affecting the distribution of deer across the landscape and the proportion of land spotlighted in each study block (Cassey and McArdle 1999). To compensate for road bias, we surveyed later in the evening when traffic was light.

The program DISTANCE 6.0 (The Distance Sampling Team, St. Andrews, Scotland, <http://www.ruwpa.st-and.ac.uk/distance/>) was used to estimate density for each block. We right-truncated the data as necessary and used the Akaike Information Criterion (AIC) to determine the best-fit model (Akaike 1973, Burnham and Anderson 2002). Buckland et al. (2001) recommended truncation to remove outliers from the analysis. We did not use left-truncation to compensate for road bias. Instead, we expanded the distance interval closest to the transect to include deer that may have shifted due to the presence of the vehicle (McShea et al. 2011). We altered model parameters, such as key function and series expansion, in order to model 2–3 different detection functions/study block and obtain an

estimate with confidence intervals of <0.25 (Thomas et al. 2010).

Impacts of Parcelization and Habitat on Density

We used ArcGIS 9.3 to determine a suite of landscape variables characterizing the 13 survey blocks. The digitized maps provided by Frederick County and Rappahannock County officials included a layer with roads and a layer mapping residential buildings. We calculated housing density by dividing the number of residential buildings in each study block by the section's area. Similarly, we calculated road density by dividing the total length of road (public and private) by the area of each study block. We reclassified the land-cover types in the 2005 Virginia Land Use Geographic Information System layer (Virginia Department of Forestry 2005) into 6 categories: forest (hardwood, pine, mixed, harvest), field (crop, grassland), development (pavement, residential, industrial), grazed pasture, apple orchard, and other. Land-cover resolution was 15×15 m². The land-cover data defines forest as an undeveloped area with trees occupying $>75\%$ of the cover (Virginia Department of Forestry 2005). The Department of Forestry data did not distinguish grazed pasture and apple orchard from cropland, so all plots of cropland along public roads within the study blocks were visually inspected and placed into the appropriate category. We summed the number of pixels within each study block to determine the percent cover of each land type.

Three parameters of human development (mean parcel size, housing density, and road density) and 3 land-cover variables (percent forest cover, field cover, and orchard presence-absence) characterized each study block. The mean and median parcel sizes of each survey block were highly correlated ($r = 0.87$), and there was no statistical difference when each metric was used as the indicator of parcel size. Due to a significant correlation between mean parcel size, housing density, and road density ($|R| > 0.840$), we selected the single variable, mean parcel size, to represent these parameters in our model. Parcel size is a straightforward measure and easily estimated at county planning offices.

We used simple and multiple linear-regression analysis to develop a model explaining the relationship between deer density (natural log) and 4 independent landscape metrics: mean parcel size, percent forest cover, percent field cover, and orchard presence-absence. We selected these parameters because they make biological sense, as prior research indicates that human development and land cover impact deer density (Vogel 1989, Roseberry and Woolf 1998, Harden et al. 2005, Storm et al. 2007b). We ranked models using the AIC and considered all models with $\Delta AIC < 2$ as competitive (Akaike 1973). Model analysis presented us with 7 competing models.

RESULTS

Hunting Data

Surveys were completed by 1,343 landowners, providing 2009 deer harvest data for 30–70% of all the land in each study block. Seventy-two percent of all the landowners contacted completed surveys, and 95% of the uncompleted

Table 1. Property parcels, pooled into 7 size classes, in the 13 study blocks of mean size 34.8 km² in northern Virginia, USA, 2009–2011. Study blocks were used to examine correlates between land parcelization, deer density, and hunting patterns.

Size class (ha)	Land parcels	
	No. surveyed	Total no. parcels
<2.0	1,437 ^a	2,933
2.0–4.0	186	1210
4.1–8.0	223	556
8.1–20.2	211	460
20.3–60.7	158	334
60.8–161.8	76	125
>161.8	20	25

^a Ninety-three percent of the parcels are in one study block (Fred.8).

surveys were from the direct mailings. Properties of all size classes were surveyed (Table 1) and 78% of survey landowners allowed us to use spotlights to survey for deer. Surveying methods varied in success; door-to-door efforts resulted in the most completed surveys (45%), followed by the voting polls (21%) and direct mailings (18%). A considerable portion (60–95%) of the surveyed land in each study block was harvested for deer, while harvest density, as identified by landowners who harvested 0–100 deer from individual property parcels, ranged from 5.8 deer to 20.5 deer harvested/km² (Table 2).

Parcel Size and Deer Harvest

Parcel size in each study block followed a unimodal probability distribution with means ranging from 2.00 ha to 26.12 ha ($\bar{x} = 11.96$ ha; Table 3). When all 13 study blocks were considered, we had deer harvest data (2009) for 2,311 property parcels.

The percentage of land hunted differed between property size classes. On average, when properties <2.0 ha were pooled, 16% of the total land area was hunted and the percent steadily increased with hunting occurring on 100% of the

land comprising parcels >161.8 ha ($F_{6,81} = 39.947$, $P < 0.001$; Fig. 1). There were differences between the property size classes, as the likelihood of hunting increased with parcel size (Fig. 1).

Harvest density did not increase with parcel size; rather, it was greatest for the 2.0–4.0-ha size class ($\bar{x} = 23$ deer/km²) and declined as property size increased ($F_{6,83} = 2.486$, $P = 0.029$; Fig. 1). Harvest density was comparable between most size classes, but 2.0–4.0-ha parcels had higher harvest densities than did 60.8–161.8-ha properties ($P = 0.023$). When the data from all the study blocks were pooled, the mean harvest density was 10.17 deer/km² and 7.14 deer/km² for Frederick and Rappahannock counties, respectively.

Across the survey blocks, the likelihood of a 0.25-km² grid cell containing land that prohibited hunting ranged from 0.124 to 0.534 (Table 2). The relationship between mean parcel size and the likelihood of a cell containing land that was not hunted was evident; for every 1-ha increase in mean parcel size, the likelihood of a grid cell containing land that was not hunted for deer declined by 0.010 ($P = 0.009$; $R^2 = 0.425$).

Parcelization Influences Deer Density

Deer densities in the survey blocks during the pre-rifle season (Oct) ranged from 9.4 deer/km² to 30.1 deer/km² (Table 2). Seven models fitting mean parcel size, forest cover, field cover, and orchard presence–absence with deer density (natural log) had comparable fits (Table 4). Based on previous studies (Lopez et al. 2004, Storm et al. 2007b, Gorham and Porter 2011), it is not surprising that habitat was a factor influencing deer density in 6 of the 7 competing models. What is surprising, is that mean parcel size (M) contributed to the top model through the linear function $y = 2.994 - 0.0188 \times M$ ($P = 0.208$, $R^2_{11} = 0.062$) and was a contributor to all the competing models where it was combined with habitat measures. Although we examined a linear fit for straight-forward comparisons between models,

Table 2. Deer harvest and density in 13 study blocks in northern Virginia, USA, 2009–2011. Study blocks were used to examine correlates between land parcelization, deer density, and hunting patterns.

Study block	Area harvested ^a (km ²)	Harvest density ^b	Refuge likelihood ^c	2010 deer density			
				No. sightings	No./km ²	LCL–UCL ^d	CV ^e
Fred.1	19.0 (85.7)	7.5	0.286	42	11.99	8.71–16.51	0.162
Fred.2	5.9 (90.7)	20.5	0.185	41	30.10	19.39–46.72	0.223
Fred.3	10.7 (65.4)	8.5	0.444	44	11.70	7.54–18.16	0.191
Fred.4	30.5 (95.4)	10.1	0.124	41	13.49	8.55–21.29	0.231
Fred.5	13.5 (81.0)	6.1	0.352	45	9.40	6.57–13.46	0.180
Fred.6	12.1 (81.4)	17.0	0.373	43	12.99	7.89–21.39	0.221
Fred.7	9.4 (64.7)	7.6	0.476	44	18.96	13.16–27.31	0.182
Fred.8	10.1 (57.0)	11.2	0.534	47	18.63	13.78–25.18	0.152
Fred.9	17.9 (87.1)	8.8	0.337	49	26.81	16.40–43.84	0.249
Fred.10	19.6 (89.2)	11.3	0.324	53	27.62	18.77–40.64	0.196
Fred.11	7.4 (76.1)	9.0	0.377	42	14.44	9.60–21.72	0.203
Rapp.West	26.1 (76.8)	5.8	0.319	62	13.36	7.73–23.07	0.174
Rapp.East	22.0 (83.7)	8.9	0.299	44	12.17	9.17–16.14	0.142

^a No. in parentheses is the portion of land harvested of all surveyed land in the study block.

^b Harvest density is the no. of deer harvested/km².

^c Refuge likelihood is the likelihood of a 0.25-km² grid cell containing land with no hunting.

^d LCL and UCL refer to the lower and upper 95% confidence intervals.

^e CV is the coeff. of variation.

Table 3. Attributes of 13 study blocks of land in Northern Virginia, USA, 2009–2011. Study blocks were used to examine correlates between land parcelization, deer density, and hunting patterns.

Study block	Land parcels			Forest cover (%)	Road density (km/km ²)	Housing density (no. houses/km ²)
	\bar{x} size (ha)	<i>n</i>	SD			
Fred.1	13.38	284	46.9	76.0	1.34	6.05
Fred.2	9.45	236	21.9	63.7	1.40	8.89
Fred.3	4.98	718	18.3	65.1	1.77	18.80
Fred.4	26.12	182	135.1	91.6	0.64	3.00
Fred.5	11.14	246	19.9	79.1	1.46	6.97
Fred.6	11.20	292	20.1	82.5	1.38	6.15
Fred.7	7.68	420	20.7	61.1	1.45	12.27
Fred.8	2.00	1657	11.1	73.0	2.23	17.17
Fred.9	5.82	636	19.0	78.3	1.49	15.81
Fred.10	10.03	321	21.8	75.1	1.36	9.47
Fred.11	8.65	203	18.4	74.5	1.47	10.46
Rapp.W	24.12	235	61.7	59.9	0.77	3.96
Rapp.E	20.87	213	61.3	63.6	0.87	3.52

the relationship between deer density and parcel size may also be explained using a curvilinear function that includes non-linear terms such as $y = 6.519 \times M \times e^{(-0.118 \times M)}$ (Fig. 2). The regression coefficients are different from 0 ($P = 0.005$ and $P < 0.001$, respectively), which suggests that the non-linear coefficient contributes to the fit of the model.

DISCUSSION

Parcel Size, Harvest Density, and Deer Density

The impact of subdivided property parcels on hunting practices and deer densities was evident, because smaller parcel size correlated with increased housing density, increased road

density, and a reduced percentage of land hunted. We found that decreased parcel size resulted in increased deer densities, supporting the conclusions of Kretser et al. (2008) that exurban development creates prime habitat for human-adapted species such as deer. These results further support the conclusion of Vogel (1989), who found that deer population densities increased as housing density shifted from low to intermediate. Development in exurbia creates prime deer habitat; although tree cover is limited in areas of high development, exurbia creates a landscape that couples forest cover with abundant food resources (Storm et al. 2007*b*). This intermixing of cover and feeding habitat maximizes deer maneuverability through a landscape (Gorham and Porter 2011).

The relationship between parcel size and harvest density was weak. Although less land was hunted for deer when parcel size was reduced, increased harvest efficiency may have helped maintain harvest density. Harvest density can be high in smaller parcels due to a more fragmented landscape and increased deer vulnerability (Foster et al. 1997). Furthermore, property owners selectively permit hunting on private property, a trait that tends to limit the number of hunters and the total deer harvest on large properties.

The model explaining deer density (natural log) in relation to mean parcel size was not significant. A curvilinear model may be more appropriate, because our results indicate that for the smallest parcels, where housing and road densities are

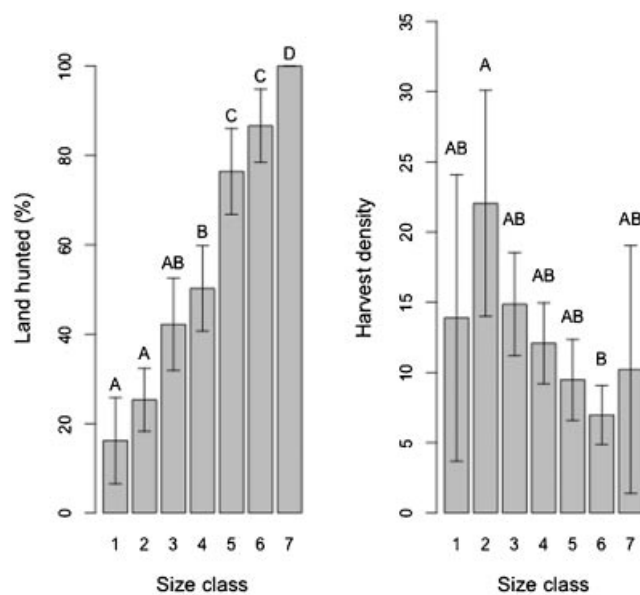


Figure 1. Properties pooled by parcel size within each northern Virginia, USA, study block, 2009–2011. One represents the smallest parcels, and 7 represents the largest parcels. The figures show both the mean percentage of land hunted for deer within each of the 7 size classes (left figure) and the mean harvest density (no. deer harvested/km²; right figure). The error bars represent the upper and lower confidence intervals. Means with different letters are different ($P < 0.05$).

Table 4. Candidate linear models with ΔAIC (Akaike Information Criterion) < 2 that predict deer density (natural log) in 13 study blocks in northern Virginia, USA, 2009–2011.

Variable	ΔAIC	K^a
Mean parcel size	0.00	1
Forest cover	1.70	1
Mean parcel size and orchard presence-absence	1.74	2
Mean parcel size and forest cover	1.86	2
Mean parcel size and field cover	1.91	2
Field Cover	1.92	1
Orchard presence-absence	1.96	1

^a K indicates the no. of predictor variables in the model.

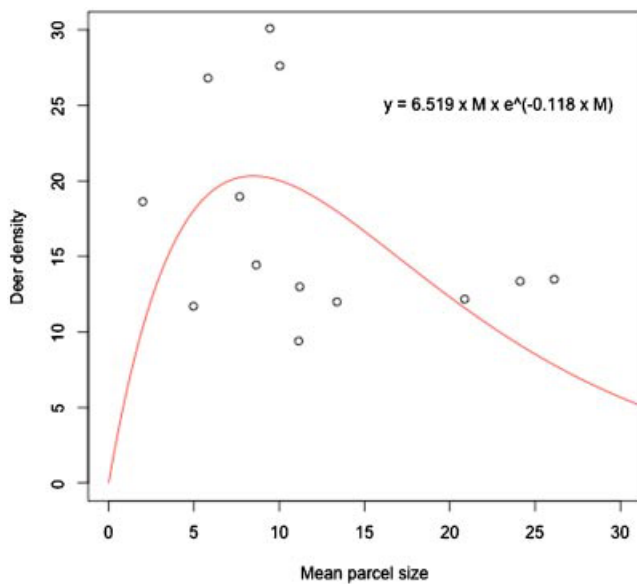


Figure 2. Relationship between mean parcel size (ha) and deer density (no. deer/km²) in 13 Virginia, USA, study blocks, 2009–2011.

highest, the relationship between mean parcel size and deer density shifts. There appears to be a threshold: deer density declines when mean parcel size drops below 7 ha. Prior studies have found a similar shift in deer densities at high levels of development. In Carbondale, Illinois, USA, Anderson et al. (2011) found that deer land use was high in areas with well-spaced human dwellings, but once human development became clumped, deer presence declined. Similarly, studies in Montana (Vogel 1989) and Florida (Lopez et al. 2004) found that deer presence was highest at intermediate levels of human development. Particularly during the non-winter months, deer avoid landscapes in close proximity to human dwellings (Storm et al. 2007b), where there is less connectivity between forest patches and a reduced quality of habitat (Gorham and Porter 2011). This tipping point weakens our linear model and may lead to an overestimate in deer density when parcelization is extensive.

We believe the general increase in deer density as mean parcel size declined was due to a patchwork in landowner decisions regarding deer management. In developing rural landscapes, increased parcelization has coincided with decreased hunter access to land (Harden et al. 2005, Jagnow et al. 2008, Campa et al. 2011), limiting the efficacy of population reduction and deer management efforts (McCullough 1984, Brown et al. 2000, Storm et al. 2007a, Bowman 2011). Individual parcels and subdivisions with ownership restrictions preventing deer harvest effectively create deer refuges. Deer refuges include properties where hunting is forbidden, as well as virtual refuges where individual hunters cannot move across the landscape to access other properties. Our study indicates that as mean parcel size declined, the likelihood of refuge presence within a 0.25-km² grid cell significantly increased. Previous research in an exurban community of Illinois found that a prevalence of properties forbidding hunting resulted in a high annual deer survival rate because the entire home range of a deer

existed on private property where there was little threat of harvest (Storm et al. 2007a). The consequences of subdividing deer habitat are less land open for deer harvest, hunting blocks becoming more isolated, and deer density increasing (Jagnow et al. 2008, Campa et al. 2011).

Landowner and Spotlighting Surveys

Our survey results indicate that deer harvest ranges from 32% to 131% of the pre-hunt population estimates. Reported harvest densities in our study were significantly higher than those derived from harvest data provided by the Virginia Department of Game and Inland Fisheries for the 2009–2010 hunting season. Overall deer harvests reported by landowners, managers, and tenants may be over-estimates (Rupp et al. 2000). For the purpose of this study, relative harvest density is more important than precise harvest density and should be comparable across study sections.

Techniques to determine deer harvest, whether through check stations, surveys, mailings, telephone calls, or report cards, have long been debated by wildlife managers (MacDonald and Dillman 1968, Rupp et al. 2000). The potential for inflated hunter success and non-response bias remain concerns during survey efforts (Rupp et al. 2000). Seventy-six percent of our surveys were from door-to-door efforts, telephone calls, and the voting polls where >95% of surveys were completed and where we did not target the hunting population. Although non-response bias is less of a concern from these efforts, it may have arisen in the mailed surveys. Mailed surveys accounted for <20% of the total surveys, and we have no reason to believe that resulting biases in harvest reports varied between study sections.

Our study further demonstrates that spotlighting is a feasible method for surveying deer density in a landscape of private property. There is a potential bias in the density estimates because the spotlighting surveys were limited to public roads, violating the assumption of DISTANCE that the survey line traverses an area with a random distribution of habitats and land uses (Buckland et al. 2001). Wildlife managers face such limitations when spotlighting in a matrix of private property where surveys are restricted to public roads. Changes in regulations to allow federal and state employees to spotlight from public roads would simplify the process of density estimation, but with the support of law enforcement officers, landowner permissions along survey routes can be secured.

MANAGEMENT IMPLICATIONS

As human populations grow, developments expand, and land becomes increasingly parcelized, deer-human conflicts will challenge wildlife managers in suburban and exurban regions (Harden et al. 2005, Anderson et al. 2011). Concerns regarding CWD and disease spread further emphasize the importance of understanding the variables that impact deer population size (Williams et al. 2002). To effectively reduce herd size through regulated hunting, wildlife managers must consider the factors that affect deer density at small scales. Parcelization restricts hunter access to land

(Harden et al. 2005, Jagnow et al. 2008, Campa et al. 2011); thus, managers aiming to control deer densities should focus their activities on gaining hunter access to smaller parcels, particularly parcels <8 ha. The highest deer densities in rural Virginia, and therefore the greatest potential for human–deer conflicts and disease spread, occurred when parcel size ranged from 5.0 ha to 10.0 ha. Planning agencies should be made aware of the consequences of subdividing land on the ability of wildlife managers to regulate deer.

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