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Original Article

Effects of Seasons and Hunting on Space Use by Female White-Tailed Deer in a Developed Landscape in Southeastern Nebraska

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ABSTRACT White-tailed deer (*Odocoileus virginianus*) were extirpated from a 1,800-ha natural area along the Missouri River near Omaha, Nebraska, USA shortly after settlement in the mid-1800s, but they recolonized the area in the early 1960s. In absence of hunting and predators, the population of deer became overabundant in the 1980s and 1990s. Deer impacted plant communities at Fontenelle Forest (FF) and Gifford Point (GP) and a 200–300% increase in deer–vehicle collisions was observed in the area. We radiocollared female white-tailed deer in this region during February 1995–March 1996 to determine the effects of phenological seasons and archery and muzzleloader hunting on space use. Mean size of annual home ranges of 50 radiocollared female deer was 275 ha (range = 18–4,265 ha, SE = 88). Forty-one of 50 deer (82%) maintained high fidelity to their small annual home ranges ($\bar{x}$ = 115 ha, SE = 13) and made short seasonal movements (<1.0 km). Seven deer dispersed and exhibited large seasonal shifts in centers of home ranges ($\bar{x}$ = 3.2 km, range = 1–7 km) and 2 deer exhibited migratory behavior. We observed no spatial patterns associated with seasonal dispersal or migration that would subject deer in unhunted areas to harvest in hunted areas. Controlled deer hunts were implemented in the upland areas adjacent to Bellevue residential area and the lowlands of FF and GP. Effects of archery hunting on deer use areas were minimal. Deer subjected to muzzleloader hunting increased the size of use areas by 88–97% and shifted centers of use areas a mean of 666 m (SE = 211, range = 121–1,932 m), but they did not leave the lowland areas of FF or GP. Controlled hunts enabled the removal of resident deer from populations adjacent to the Bellevue residential area. Where practical, we suggest that regulated hunting be used as part of an overall plan to manage densities of deer and associated impacts in developed landscapes.

KEY WORDS developed landscapes, dispersal, home range, hunting, Nebraska, *Odocoileus virginianus*, suburban, white-tailed deer.

The occurrence of overabundant white-tailed deer (*Odocoileus virginianus*) in developed landscapes is an increasingly frequent phenomenon in North America (Conover 1993, Porter et al. 1994, Warren 1997). Problems associated with overabundant deer, such as damage to personal property and plant communities (Connelly et al. 1987, Stromayer and Warren 1997, Waller and Alverson 1997), deer–vehicle collisions (Bashore et al. 1985; Etter et al. 2000, 2002), and disease transmission (Menzel and Havel 1977, Gladfelter 1984, Nettles 1997) have created demand for research and management to reduce negative impacts. During the 1990s, these problems arose in and around a 1,800-ha natural area associated with Fontenelle Forest (FF), Gifford Point Wildlife Management Area (GP), and adjacent parks and other green space along the Missouri River, near Omaha and Bellevue, in eastern Nebraska, USA (Fig. 1). In particular, increases of 192% and 325% in deer–vehicle collisions caused concern in Sarpy County and the community of Bellevue, Nebraska from 1984 to 1994, respectively (Hygnstom and VerCauteren, Bellevue Deer Task Force, unpublished report).

In 1992, noted conservation biologist Jared Diamond visited FF. He was impressed with its overall beauty, but dismayed by the ecological condition of the forest, noting that overabundant deer were degrading the forest and causing "reverse succession" (Diamond 1992). Persistent browsing by deer was preventing regeneration of overstory species such as bur oak (*Quercus macrocarpa*), shagbark hickory (*Carya ovata*), and American linden (*Tilia americana*). These dominant species were being replaced by mid-level

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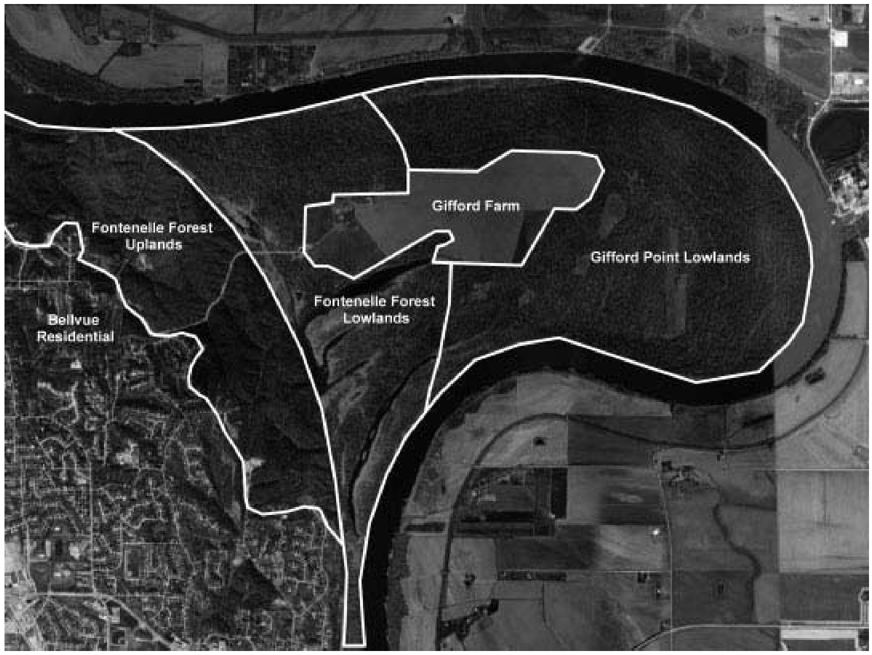

Figure 1. The 1,800-ha study area consisted of Fontenelle Forest (FF) lowlands and uplands, Gifford Point (GP) lowlands, Gifford Farm (GF), and Bellevue residential (BR) area near Omaha and Bellevue, Nebraska, USA, 1995–1997.

hackberry (*Celtis occidentalis*) and ironwood (*Ostrya virginiana*). Deer-resistant snakeroot (*Sanicula* spp.), barberry (*Berberis thunbergii*), garlic mustard (*Allaria petioata*), and tree of heaven (*Ailanthus altissima*) were increasing, while less resistant native woodland forbs were disappearing (Gubanyi 2001, Gubanyi et al. 2008). At densities >8.5 deer/km^2, white-tailed deer prevent recruitment of saplings and small trees of preferred browse species of trees (Anderson and Loucks 1979, Tilghman 1989, Russell et al. 2001).

Aerial censuses of deer in FF and GP during January 1965 ($n = 161$) and January 1982 ($n = 158$) revealed that deer were distributed primarily in lowlands of GP during winter (N. Dey, Nebraska Game and Parks Commission [NGPC], personal communication; Fig. 1). Managers speculated that the population of deer increased dramatically in the late 1980s and some deer shifted their home ranges into wooded uplands of FF and adjacent residential areas and began to reproduce within the subdivisions of Bellevue, Nebraska. In January 1995, we conducted a helicopter survey and counted 495 deer distributed throughout the study area (27 deer/km^2; VerCauteren and Hygnstrom 2000). Area managers believed deer migrated from GP lowlands in spring to FF uplands for summer, before returning to GP lowlands in autumn to overwinter. The GP Habitat Management Preliminary Action Plan (NGPC 1990) identified a need for research to determine whether deer that spent spring and summer in unhunted uplands and lowlands of FF were available to be harvested in lowlands of GP during autumn archery and muzzleloader hunting seasons. Our objectives were to determine 1) annual home ranges of white-tailed deer, 2) whether seasonal movements would subject upland deer to harvest in hunted lowland areas, and 3) spatial response of deer to controlled hunts, in a developed landscape in southeastern Nebraska. We predicted that home ranges, use areas, and movements of white-tailed deer would be similar across phenological and hunting seasons in FF and GP.

STUDY AREA

Our study area was adjacent to the Missouri River and bounded by Omaha, Nebraska to the north and Bellevue, Nebraska to the west (Fig. 1). The study area consisted of 3 vegetative zones (FF uplands, FF lowlands, and GP lowlands) along with an adjacent Bellevue residential area that consisted of considerable green space associated with a Boy Scout camp, Girl Scout camp, city park, golf course, and individually owned residential tracts. Fontenelle Forest was a 736-ha privately owned natural area and conservation education facility that consisted of equal proportions of forested floodplain and wooded uplands. Fontenelle Forest was traversed by 27 km of hiking trails. Environmental education and public recreation were primary land uses, with nearly 60,000 visitors annually. Prior to our research, hunting had not been allowed in FF since its inception in 1921. The 509-ha GP Wildlife Management Area was located in the forested floodplain of the Missouri River and was managed by the NGPC for wildlife and hunting. Gifford Farm, a 162-ha agricultural area, was located between FF and GP. It was managed by the Educational Services Unit of Omaha, Nebraska and served as a youth center for agricultural education. Corn, soybeans, and alfalfa were primary crops raised on Gifford Farm. Parks, camps, residential subdivisions, acreages, a golf course, and other open areas were interspersed within upland habitat and collectively occupied about

400 ha. The residential area sloped westward into an urban business and industrial complex that bounded the study area to the west. Since 1965, housing developments increased gradually in upland areas and eventually surrounded previously rural areas that had consisted of orchards, pastures, and natural woodlands. As subdivisions grew, much of the adjacent natural upland area was preserved for aesthetic value. We included riparian forest, floodplain, and crop areas along western edges of Mills and Pottawattamie Counties, Iowa, USA in the study area because 4 radio-equipped deer crossed the Missouri River into these areas. Primary uses of land in Iowa were high-intensity agriculture and scattered municipal and residential developments.

The study area was occupied by 550 species of vascular flora (Garabrandt 1988). Predominant plant communities included mature floodplain forest, forested river bluffs, upland suburban forest, and cultured turfgrass. The area also included floodplain agricultural fields, grassland savannas, and oxbow wetlands. Dominant tree species in the floodplain included cottonwood (*Populus deltoides*), silver maple (*Acer saccharinum*), and sycamore (*Platanus occidentalis*). Upland species included bur oak, shagbark hickory, black walnut (*Juglans nigra*) American elm (*Ulmus americana*), green ash (*Fraxinus pennsylvanica*), red elm (*U. rubra*), and hackberry. Predominant understory woody plants included ironwood, redbud (*Cercis canadensis*), red mulberry (*Morus rubra*), rough-leafed dogwood (*Cornus drummondii*), coralberry (*Symphoricarpos orbiculatus*), poison ivy (*Toxicodendron radicans*), and Virginia creeper (*Parthenocissus quinquefolia*).

White-tailed deer were uncommon in the study area from postsettlement in the mid-1800s to 1960s. Two deer were observed in lowlands of GP in 1960 (N. Dey, personal communication). The density of deer increased dramatically through the 1980s in association with ample food and cover and absence of hunting (Hygnstrom and VerCauteren 1999). In January 1995, we estimated the density of deer in the study area at 27 deer/km^2, based on a helicopter count (VerCauteren and Hygnstrom 2000). Highly controlled annual hunts were conducted to reduce deer numbers in FF beginning in autumn 1996. Hunts consisted of a 9-day archery season in uplands of FF and a 9-day muzzleloader season in lowlands of FF, both of which occurred on 4–12 December 1996. Participants were required to register daily, hunt from stationary elevated stands, and restricted to harvesting 2 antlerless deer. In 1996, 34 archers (53% success) and 13 muzzleloader hunters (77% success) harvested 28 deer in FF (Ekstein and Hygnstrom 1997). Deer hunting on GP began in 1973 and consisted of annual 108-day archery and intermittent 9-day muzzleloader and rifle seasons (Hygnstrom and VerCauteren 1999). Participants were required to register daily at Gifford Farm. Vehicle access was provided by a road that encircled Gifford Farm. Hunters were not restricted to elevated stands and were permitted to harvest either sex of deer. Hunters harvested 2,621 white-tailed deer in the GP area during 1973–1997 and in 1996, 217 archery hunters harvested 75 deer (35% success) and 59 muzzleloader hunters harvested 18 deer (31% success; Hygnstrom and VerCauteren 1999). No restrictions were placed on any hunters regarding harvest of radio-equipped deer.

METHODS

We captured 98 white-tailed deer in FF and GP during February 1995–March 1996 with netted cage traps, rocket-nets, and remote chemical immobilization. Capture efforts were distributed relatively evenly across the study area. We equipped 50 female deer, including 22 adults (>12 months old) and 28 juveniles (8–12 months old) with radiocollars (Advanced Telemetry Systems, Isanti, MN) and ear tags for individual identification. We concentrated telemetry efforts on female deer because matriarchal family groups led by adult females make up the largest proportion of deer populations and knowledge of female survival is critical for predicting changes in populations (Porter et al. 1991, Mathews and Porter 1993, Aycrigg and Porter 1997). We located radio marked females 1–4 times/week from 17 February 1995 to 31 March 1997. We increased tracking effort during crepuscular periods and at night, to fully represent home ranges when deer were most active. We obtained 2–4 receiver bearings from mapped receiving sites for telemetry-based locations with a bearing accuracy of $\pm 1.9^{\circ}$. The average time span between bearings was 5 min. We omitted all locations in which bearings were collected >10 min apart or in which error polygons exceeded 2.0 ha. We had a high degree of confidence in the accuracy of locations because about half of them were confirmed by visually observing individual deer. All methods were approved by the University of Nebraska-Lincoln Institutional Animal Care and Use Committee (UNL-IACUC no. 95-02-007).

We used Excel 5.0 (Microsoft 1997) and Spatial Ecology Analysis System (SEAS; J. R. Cary, University of Wisconsin-Madison) to generate locations of deer from telemetry data. A land-cover map and overlays of deer locations were developed using Map and Image Processing System (MIPS; MicroImages, Lincoln, NE). We calculated annual home ranges, seasonal use areas, and hunting-season–specific use areas using a harmonic mean method (Dixon and Chapman 1980). We felt this method was more appropriate than kernel-based procedures because at small samples sizes (<30, associated with seasonal use areas and hunting-season–specific use areas) kernel estimators tend to overestimate, while other methods underestimate, size of home ranges (Seaman et al. 1999). Thus, we opted for a more conservative approach. We used 95% and 50% isopleths to delineate boundaries of each annual home range and seasonal use area, respectively (White and Garrott 1990). Harmonic mean generally had the smallest bias of methods tested (Fourier series, minimum convex polygon, and Koeppl or JT ellipse) for 1 or 2 centers of activity or a square-shaped distribution (Boulanger and White 1990). The harmonic mean method produces range configurations that relate well to actual distributions of fixes and is particularly useful for calculating core areas (Harris et al. 1990). All radio-equipped deer and age classes of radio-equipped deer were relatively evenly distributed across regions of the study area (FF upland and Bellevue residential area [$n = 21$], FF lowland

[$n = 13$], and GP lowland [$n = 16$]). The study area was relatively small and confined, so we observed overlap of annual home ranges of radio-equipped deer across the area, but movements and space use of individual deer was highly variable. Therefore, we assumed that locations of deer were independent. Our approach followed similar methodology used in previous studies in which time periods were short due to crop phenology and <100 deer were being monitored (Gilsdorf et al. 2004*a*,*b*). Jacques et al. (2009) recently used harmonic means to detect shifts in activity centers of pronghorn antelope (*Antilocapra americana*) in South Dakota, USA.

We defined our seasons as nonwinter (1 Apr 1996–30 Nov 1996) and winter (1 Dec 1996–31 Mar 1997). To evaluate effects of hunting on space use, we pooled locations of deer collected during 60-day periods associated with the hunts. For the FF uplands archery, FF lowlands muzzleloader, and GP lowlands muzzleloader hunts, the "before" period was 4 October 1996 to 3 December 1996 and the "during–after" period was 4 December 1996 to 2 February 1997. For the GP lowland archery hunt, the "before" period was 1 July 1996 to 14 September 1996, the "during" period was 15 September 1996 to 31 December 1996, and the "after" period was 1 January 1997 to 14 March 1997. We measured 3 characteristics of each use area for each season and hunting period: area within the 95% isopleth, distance between arithmetic centers of selected and subsequent use areas, and percentage of overlap between 95% isopleths of selected and subsequent use areas. We used adjusted *t*-tests to determine differences in characteristics of use areas between seasons and hunting periods (Hays 1988). We plotted frequency of size of home ranges, distance between centers of use areas, and percent overlap of use areas and found data to be normally distributed. Sample variances for characteristics of use areas, however, were heterogeneous. Hays (1988) indicated that the assumption of homogeneity in variances can be violated without serious risk, provided the number of cases per treatment is equal, which they were.

RESULTS AND DISCUSSION

Annual Home Ranges

We generated 5,716 locations of 50 radio marked female white-tailed deer in the study area. Mean number of locations per deer was 118 (SE = 10, range = 29–247). Mean size of annual home ranges was 275 ha (SE = 88, range = 18–4,265 ha). Home ranges of juveniles ($\bar{x} = 288$, range = 25–1,770) were larger than those of adults ($\bar{x} = 112.7$, range = 18–442, $P = 0.0001$), likely because of their propensity to disperse. Six of the 9 transient deer were juveniles, including all those that dispersed the longest distances. Forty-one (82%) of 50 deer were residents that maintained relatively small, static home ranges ($\bar{x} = 115$ ha, SE = 13, range = 18–293 ha) and displayed minor seasonal shifts (<1.0 km). The remaining 9 deer exhibited dispersal (7) or migratory (2) behavior. Home ranges of resident deer typically had a high degree of overlap between seasons ($\bar{x} = 66\%$, range = 10–100%). During winter, one resident deer exhibited a 1-month foray that resulted in large seasonal shifts (range = 531–1,541 m) and diminished overlaps (10–34%) across seasons. Mean size of home ranges of resident deer in our study area was smaller than those in other Midwest agricultural landscapes (170 ha in Nebraska [VerCauteren 1993], 162 ha in Missouri [Progulske and Baskett 1958], and 162 ha in Iowa [Gladfelter 1978]). Cornecelli (1992) and Grund (1998) reported daily activities of urban and rural deer were similar, but urban deer had smaller home ranges. Home ranges of white-tailed deer inhabiting an urban park in Minnesota, USA were 73–111 ha (Grund et al. 2002). Female white-tailed deer typically will not leave established home ranges, even if higher quality areas are available, due to home range fidelity and social factors (Nelson and Mech 1984, 1992; Mathews and Porter, 1993; McNulty et al., 1997).

Twenty-five of the resident deer occupied lowlands of FF and GP. Fourteen resided in uplands of FF and the Bellevue residential area, and 2 occupied both upland and lowland areas of FF. Home ranges of deer in lowlands of GP predominantly were associated with wooded areas, but deer also frequented small openings and cropland in GF before completion of a woven-wire fence around the perimeter of the cropland in April 1996. Deer occupied wooded lowlands of FF and adjacent grass pastures of Gifford Farm. In uplands of FF, deer used ridges and valleys that were less developed, as well as areas interlaced with boardwalks and wooded bluffs adjacent to the Bellevue residential area. We frequently observed deer on city streets, in backyards, and at deer feeders in Bellevue during the study. Fourteen radio-equipped female deer used feeders daily at times that coincided with placement of feed.

Seasonal Movements

Nine of the 50 radio-equipped female deer at FF and GP exhibited seasonal movements, based on large shifts in centers of use areas ($\bar{x} = 3.2$ km, range = 1–7 km) and low percentage overlap in subsequent seasonal use areas ($\bar{x} = 9\%$, range = 0–38%). Mean number of locations per transient deer during the nonwinter period (Apr–Nov) was 48 (range = 22–69) and during winter was 20 (range = 15–30). Migratory deer moved between seasonal use areas, while dispersers left previously occupied home ranges without returning (Hygnstrom et al. 2008). Only 2 deer exhibited migratory behavior, including 1 adult doe, which (as speculated) occupied lowlands of GP during winter and migrated back and forth from uplands of FF during the nonwinter period, but it was the only transient deer to exhibit such directionality. Two other deer wintered in lowlands of GP and dispersed during spring, but one went south, crossed the Missouri River, and settled near cropland in Iowa while the other moved northeast, crossed the river, and settled in wooded lowlands in Iowa. The remaining transient deer wintered in FF lowlands, FF uplands, and the Bellevue residential area and dispersed in all different directions. Mean dispersal distance was 3.1 km (range = 1.7–6.7 km). Spring movements have been reported to occur in <30% of female deer in mid-latitudes (35–45°;

Gladfelter 1978, Zwank et al. 1979, Nixon et al. 1991). Females dispersed much farther at DeSoto National Wildlife Refuge (DNWR) in east-central Nebraska, ($\bar{x} = 28.5$ km, range = 3–87 km; VerCauteren 1998) than they did at FF and GP. Urban areas of Bellevue and Omaha apparently were a more significant barrier to deer movements than the Missouri River or large agricultural fields adjacent to DNWR.

Biologists in the 1970s and 1980s speculated that deer moved out of upland areas in FF and the Bellevue residential area after heavy snowfalls and congregated in stands of cottonwoods in lowlands of GP, based on aerial surveys conducted in January 1965 and 1982 (N. Dey, personal communication). Deer rarely were seen in lowlands or uplands of FF during winter in the 1970s and 1980s. Initially, NGPC biologists believed the population of deer in uplands of FF could be controlled by hunts conducted on GP because deer that migrated during autumn from FF uplands to overwinter in lowlands of GP would be available for harvest during autumn hunting seasons in lowlands of GP. By the late 1980s, however, deer were observed with increasing frequency in uplands of FF and the Bellevue residential area. Factors that influenced rapid growth of the population of deer in the area were thought to be high fecundity, absence of hunting in FF and the Bellevue residential area, availability of agricultural crops on Gifford Farm, widespread and prodigious feeding of deer in the Bellevue residential area, and new sources of food and water generated by increased residential development in Bellevue. The feeding of deer by Bellevue residents led to speculation by NGPC biologists and local resource managers that deer had lost their migratory behavior and were staying in uplands throughout the year. Only 2 of the 21 radio-equipped deer that occupied uplands of FF and Bellevue residential area exhibited migratory movements and 2 dispersed. The size of home ranges of deer in uplands of FF during winter and nonwinter periods of 1995–1996 did not differ ($P = 0.78$), nor did distances between centers ($P = 0.55$) and overlaps ($P = 0.12$) of seasonal use areas. The radio-equipped deer were distributed from north to south across the entire FF uplands and the Bellevue residential area. Grund et al. (2002) reported small shifts (229–266 m) in centers of home ranges of urban white-tailed deer in Minnesota. Eighty-two percent of the deer in our study area maintained a high degree of fidelity to home ranges in lowlands of FF and GP and uplands of FF and Bellevue residential area. Therefore, hunting in the lowlands of GP alone would not be an effective means of controlling the density of deer in the uplands of FF and the Bellevue residential area.

Effects of Hunting

Thirty-four archers and 13 muzzleloader hunters participated in hunts in FF and harvested 18 and 10 deer, respectively in 1996. They logged 1,175 visits during the 2 concurrent 9-day seasons. All were required to use stationary tree stands. No stalking, still-hunting, or deer drives were allowed, so disturbance of deer was minimal, except for when hunters moved in and out of stands, when they sat on stands, and shot at deer. Two-hundred seventeen archers and 59 muzzleloader hunters participated in hunts in GP and harvested 75 and 18 deer, respectively in 1996. Archers logged 2,838 visits during the 108-day season. Muzzleloader hunters logged 132 visits during the 9-day season. Vehicle access to the area was limited to a road that encircled Gifford Farm. Although method of hunt was not restricted, deer drives were uncommon in the area (R. Gleason, Educational Services Unit, personal communication). Six radio-equipped deer were harvested by archers in 1996, 1 in uplands of FF and 5 in lowlands of GP. One radio-equipped deer was harvested by a muzzleloader hunter in lowlands of FF in 1996.

Twenty-nine radio collared deer in our study (58%) resided in areas that were open to muzzleloader seasons (FF lowlands, $n = 5$; GP lowlands, $n = 5$) and archery seasons (FF uplands, $n = 13$; GP lowlands, $n = 13$) in 1996. Seven of the deer occupied areas that were hunted during 2 of the 4 seasons. Mean number of locations per deer was 20.2–21.1 (range = 10–30) for each of the periods (before and after) associated with hunting seasons in FF and 16.4–25.6 (range = 10–36) for each of the periods (before, during, and after) associated with hunting seasons in GP. Although the number of locations approached the minimal number needed for reasonable estimation of use areas by the harmonic mean method, they were similar among deer and across seasons. Use areas of 13 deer subjected to the 9-day archery hunt in uplands of FF increased only 11% and remained within uplands of FF. Use areas of 10 deer subjected to 9-day muzzleloader hunts increased 88% and 97% in size in lowlands of FF and GP, respectively (Table 1). Deer subjected to muzzleloader hunts in lowlands of GP

Table 1. Space use ($\bar{x}$, range) of 23 radiomarked female white-tailed deer based on 1,412 locations collected before and during–after 9-day archery and muzzleloader hunts at Fontenelle Forest uplands and lowlands (FFU, FFL) and Gifford Point lowlands (GPL), Nebraska, USA, 1996.

		Home range size (ha)					Center shift (m)		Overlap (%)			
		Before		During–after			Before–after		Before–after			
Hunt type	n	$\bar{x}$	Range	$\bar{x}$	Range	Δ (%)	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
FFU archery[a]	13	36	13–86	40	9–85	+11	164	44–595	25	7–43	69	33–100
FFL muzzleloader[a]	5	68	12–157	128	41–347	+88	237	79–871	34	10–58	81	20–100
GPL muzzleloader[a]	5	38	3–66	75	28–146	+97	666	121–1,932	18	0–44	53	0–100

[a] For the FFU archery, FFL muzzleloader, and GPL muzzleloader hunts, the "before" period was 4 Oct 1996 to 3 Dec 1996 and the "during–after" period was 4 Dec 1996 to 2 Feb 1997.

exhibited the greatest shifts in centers of use areas ($\bar{x} = 666$ m, SE = 211, range = 121–1,932 m), but use areas overlapped 53% from pre- to post hunt and remained within the lowlands of GP (Table 1). Mean size of use areas of female white-tailed deer at DNWR in east-central Nebraska did not differ before and after annual muzzleloader hunting seasons but shifts in centers of use areas were observed ($\bar{x} = 194$ m; VerCauteren and Hygnstrom 1998). Due to the short duration of 9-day muzzleloader seasons, we were unable to collect enough data to generate reliable use areas during hunts. We observed 13 deer subjected to a 108-day archery hunt in lowlands of GP, which enabled collection of a sufficient number of locations ($\bar{x} = 87$, SE = 20, range = 23–199) to establish reasonable use areas during the hunt. Use areas of these deer decreased in size by 39%, from during ($\bar{x} = 87$ ha) to after ($\bar{x} = 46$ ha) the hunt. The centers of during- to after-hunt use areas moved 547 m, overlapped by 40%, and all remained in the lowland of GP. Archery hunting in a suburban area of Connecticut, USA had minimal effect on use areas of white-tailed deer (Kilpatrick and Lima 1999). They found 80% of deer remained within their annual home ranges during the 9-week season but shifted their core areas to locales with little or no hunting pressure.

In general, effects of archery hunting on space use by white-tailed deer in our study were minimal, whereas short-term impacts of muzzleloader hunting were considerable. Most deer, however, maintained high fidelity to home ranges, even when subjected to disturbance associated with archery or muzzleloader hunting. Movements of deer subjected to hunting pressure may be linked to habitat type, frequency of encounters with hunters, or the degree of previous human exposure (Kilpatrick and Lima 1999). Deer in lowlands of GP experienced little interaction with humans until autumn hunting seasons and contact with muzzleloader hunters likely resulted in avoidance responses. In contrast, deer in uplands of FF were subjected to high levels of human activity (e.g., hikers, boardwalk visitors, and school groups) throughout the year and were often fed in the Bellevue residential area. As a result, many deer in uplands of FF and Bellevue residential areas likely were more acclimated to human activities and disturbance associated with archery hunts had little impact on use of space by these deer.

Regardless of possible negative effects of feeding deer (Nettles 1997), the activity is legal in Nebraska, and likely had affected space use by deer in FF uplands and the Bellevue residential area. Ironically, it is illegal to use bait while hunting deer in Nebraska. Baiting is legal in several states and could be used in controlled hunts in developed landscapes to increase success in harvesting overabundant deer.

MANAGEMENT IMPLICATIONS

Knowledge of movements of individual animals can facilitate population management. Eighty-two percent of radio-marked female white-tailed deer in our study were residents of FF or GP. Emigration rates were low, even though densities of deer were high. Therefore, increased mortality was needed to reduce densities and maintain deer at levels conducive to land management goals and social carrying capacity. Deer used upland forest and adjacent residential areas year-round. We detected no seasonal patterns of migratory or dispersal behavior in deer using uplands of FF or Bellevue residential area. Therefore, deer that used upland areas were not susceptible to public hunting that occurred during autumn in lowlands of GP. After the introduction of hunting on FF, densities of deer in the study area declined from 27 deer/km^2 in 1995 to 14 deer/km^2 in 1998 (VerCauteren and Hygnstrom 2000). Given current harvest restrictions, as well as real and perceived problems caused by overabundant white-tailed deer, it will be necessary for associated agencies and organizations to coordinate management programs and reduce numbers of deer to achieve the goal of 10 deer/km^2. Given high cost, limited effectiveness, and unintended consequences of alternative methods of reducing deer populations (i.e., fertility control, trap and translocate, Craven and Hygnstrom 1994, DeNicola et al. 2001) we recommend that regulated hunting seasons be continued in uplands of FF and expanded to include adjacent open spaces of the Bellevue residential area.

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