Behavioral responses of white-tailed deer subjected to lethal management

Scott C. Williams, Anthony J. DeNicola, and Isaac M. Ortega

Abstract: Currently, the most effective and cost-efficient mechanism for controlling overabundant white-tailed deer (*Odocoileus virginianus* (Zimmermann, 1780)) is lethal removal, most commonly controlled hunting and sharpshooting. Deer subjected to such efforts may behave differently during removal and remaining deer may alter behaviors, potentially limiting future efficacy of removal efforts. Our objectives were to quantify changes in deer distribution in response to controlled hunting and sharpshooting. We immobilized two sample populations of 20 deer (one enclosed and one free-ranging) in central New Jersey, USA, and fitted them with global positioning system collars. The free-ranging herd experienced 11 days of controlled hunting, reducing density from 78 to 27 deer/km^2. We subjected the enclosed herd to a 7 day sharpshoot, reducing density from 83 to 7 deer/km^2. Hunted deer increased mean home ranges during removal, while deer exposed to sharpshooting did not. Collared doe–doe home-range overlap increased postsharpshoot, suggesting increased social interaction. Behaviors of hunted deer were directly affected by the human threat, while behavioral changes of deer exposed to sharpshooting were linked to population reduction. In the absence of an intact matrilineal social group, unrelated does will seek each other out in what appears to be an inherent need to be social.

Résumé : À l'heure actuelle, le mécanisme le plus efficace et le plus économiquement rentable pour contrôler la surabondance des cerfs à queue blanche (*Odocoileus virginianus* (Zimmermann, 1780)) est le retrait par élimination, le plus souvent par chasse contrôlée ou par tir de précision. Les cerfs affectés par ces mesures peuvent se comporter différemment durant les retraits et les cerfs survivants modifier leur comportement, ce qui potentiellement peut limiter l'efficacité des opérations futures de retrait. Nos objectifs sont de déterminer les changements de répartition des cerfs en réaction à la chasse contrôlée et aux tirs de précision. Nous avons immobilisé des échantillons de 20 cerfs chacun de deux populations (une en enclos et l'autre libre en nature) dans le centre du New Jersey, É.-U., et les avons munis de colliers avec système de positionnement global. La population libre en nature a connu 11 jours de chasse contrôlée qui a réduit la population de 78 à 27 cerfs/km^2. Le troupeau en enclos a été soumis pendant 11 jours à des francs-tireurs qui ont réduit la densité de 83 à 7 cerfs/km^2. Les cerfs chassés ont augmenté leur domaine vital moyen durant le retrait, alors que les cerfs soumis aux tirs de précision ne l'ont pas fait. Le chevauchement entre les domaines vitaux des biches porteuses de collier a augmenté après le passage des francs-tireurs, ce qui laisse croire à un accroissement des interactions sociales. Les comportements des cerfs chassés sont affectés directement par la menace représentée par les humains, alors que les changements de comportement chez les cerfs exposés aux francs-tireurs sont reliés à la réduction de la population. En l'absence de groupe social matrilinéaire intact, les biches non apparentées recherchent la présence mutuelle les unes des autres dans ce qui semble être un besoin inhérent de sociabilité.

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Introduction

An overabundance of white-tailed deer (*Odocoileus virginianus* (Zimmermann, 1780)) in the northeastern United States has negatively affected native ecosystems and human health for decades (Anderson et al. 1987; Conover et al.

S.C. Williams[1,2] and I.M. Ortega. Department of Natural Resources Management and Engineering, University of Connecticut, 1376 Storrs Road, Unit 4087, Storrs, CT 06269-4087, USA.
A.J. DeNicola. White Buffalo, Inc., 26 Davison Road, Moodus, CT 06469-1035, USA.

[1]Corresponding author (e-mail: scott.williams@po.state.ct.us).
[2]Present address: Department of Forestry and Horticulture, The Connecticut Agricultural Experiment Station, 123 Huntington Street, New Haven, CT 06504, USA.

1995; Ward 2000; Magnarelli et al. 2004). Overabundant deer can significantly decrease forest species diversity, regeneration, and economic value by preferential browsing on economically desirable species such as oak (genus *Quercus* L.), white pine (*Pinus strobus* L.), and to a lesser extent sugar maple (*Acer saccharum* Marsh.) (Williams et al. 2006). This encourages the growth of nonpalatable and less economically desirable species such as striped maple (*Acer pensylvanicum* L.), American hornbeam (*Carpinus caroliniana* Walt.), hophornbeam (*Ostrya virginiana* (P. Mill.) K. Koch), and American beech (*Fagus grandifolia* Ehrh.) (Kelty and Nyland 1983; Kittredge et al. 1992). Increased deer densities can cause significant economic damage to both agricultural crops and landscape plantings (DeNicola et al. 2000; Ward 2000). In addition, deer play an important role in the dispersal of viable seeds of exotic plants (Williams and Ward 2006; Williams et al. 2008).

Deer are hosts for adult blacklegged ticks (*Ixodes scapularis* Say, 1821; commonly referred to as deer ticks), which transmit the causal agents of Lyme disease (Stafford 1993;

Stafford et al. 2003), human granulocytic anaplasmosis (Belongia et al. 1997; Little et al. 1998; Stafford et al. 1999; Magnarelli et al. 2004), and human babesiosis (Anderson et al. 1987; Stafford et al. 1999). Nationwide, at least 1.5 million deer/vehicle collisions occur annually, resulting in 1.3 million deer deaths, $1.1 billion in vehicle damage, 29 000 human injuries, and over 200 human fatalities (Conover et al. 1995).

Many communities nationwide must decide how to handle human–deer conflicts. There are diverse opinions among members of the public on how deer populations should be managed based on their personal beliefs (Purdy and Decker 1989; Curtis et al. 1997; DeNicola et al. 2000). Some residents may be advocates of lethal control of animals, while others may prefer nonlethal techniques. As a result, numerous deer management options have been explored, each with their own advantages and disadvantages. Regardless of which management approach is taken, if top–down limitation is insufficient to prevent deer population overabundance, available forage will become severely depleted, leading to increased disease susceptibility, malnutrition, and the eventual starvation of individuals within the herd (Davidson and Doster 1997; Healy 1997; Palmer et al. 1997; DeNicola et al. 2000).

Hunting is a proven management tool in both rural (Roseberry et al. 1969; McCullough 1984; Kufeld et al. 1988; VerCauteren and Hygnstrom 1998) and some suburban areas (Kuser 1995; Mayer et al. 1995; Kilpatrick and Walter 1999). However, hunting may not be feasible, legal, or socially acceptable in many locations, particularly residential areas (Kuser 1995; Mayer et al. 1995; Kilpatrick et al. 1997; Messmer and Hewitt 1998). Currently, lethal removal remains the most efficient and cost-effective means of local herd control, as results are immediate (DeNicola et al. 1997, 2000). It is unlikely that any community would want deer completely eliminated, but rather reduced to ecological carrying capacity or to a socially desirable level. As such, it is imperative to understand how remaining animals will behave to different harvesting methods to plan effective management strategies.

While controlled hunting can be successful at reducing deer densities in localized areas (Sigmund and Bernier 1994; Kilpatrick et al. 1997), sharpshooting techniques can give managers greater control, thereby allowing for removal of a greater proportion of animals (Butfiloski et al. 1997; Frost et al. 1997; DeNicola and Williams 2008). Following density reduction, remaining white-tailed deer will most often increase home-range size (Marchinton and Jeter 1967; Marshall and Whittington 1968; Bertrand et al. 1996; Williams and DeNicola 2002), as is the case with most mammalian species (Sanderson 1966). In addition, Behrend et al. (1970) and Porter et al. (1991) reported that animals remaining postharvest exhibited high home-range site fidelity and did not expand into adjacent areas with lower densities. However, on other research sites, we have witnessed deer remaining postharvest shifting out of known home ranges to associate with unrelated individuals.

The main goal of this research was to quantify changes in the distribution of white-tailed deer in response to controlled hunting and sharpshooting at significantly reduced densities. We hypothesized that deer remaining postharvest would be inclined to interact with members of other matrilineal groups owing to a loss of social counterparts by increasing areas of shared home-range overlap. We also hypothesized that these social behaviors would be strong enough to shift deer out of known core ranges to accommodate the new social network.

Materials and methods

Study area

The study occurred at Duke Farms, a 1093 ha private estate located in Hillsborough, New Jersey (40°33′N, 74°38′W), which was surrounded by high-density residential housing and commercial development. A portion of the property (283 ha, referred to as the Park) was more than 50% deciduous forest, gated, enclosed by a 3 m fence, and had an initial density of 83 deer/km². Density estimation was achieved by a total count of harvested and collared animals. The Park was about 40% agricultural, which included gardens, field crops, and lawns. The remaining 810 ha (referred to as the Farm) were unfenced and consisted of nearly 70% hayfields and ~20% deciduous forest, had public roads running throughout, and an estimated 78 deer/km². Deer density was established using forward-looking infrared radar (FLIR) counts throughout the study (Naugle et al. 1996; Havens and Sharp 1998). Duke Farms had a broad array of ornamental plantings throughout the property, particularly in the Park. Because of intolerable browse damage, increased numbers of blacklegged ticks and associated disease-causing organisms, increased collisions with vehicles, and virtual absence of ground and low-level nesting birds, the managers of the Estate decided to extirpate all deer from the Park using sharpshooting techniques and reduce Farm densities via controlled hunting. The presence of the enclosed herd provided a unique research opportunity, as it provided more control over research animals and limited immigration and emigration. Managers of the Estate agreed to delay complete extirpation of the Park herd for 1 year so that this study could be conducted.

Deer capture and collaring

In late November 2004, we captured 20 animals reflecting the local sex ratio and age demographic (8 adult does, 4 adult bucks, 4 doe fawns, 4 buck fawns) both within the Park and Farm. Deer were immobilized opportunistically from a vehicle or from a tree stand over established bait sites using a dart rifle system (Pneu-Dart Inc., Williamsport, Pennsylvania) equipped with a 4-power scope. Darts (2 cc, where 1 cc = 1 mL) contained a combination of 367 mg zolazepam hydrochloride and tiletamine hydrochloride (Telazol®; Fort Dodge Animal Health, Fort Dodge, Iowa) and 220 mg xylazine hydrochloride (Rompun®; Bayer Corp., Pittsburgh, Pennsylvania). Some darts contained a transmitter for aid in locating the sedated animal (Kilpatrick et al. 1996). We blindfolded sedated deer and applied Puralube® (Fougera, Melville, New York) to the eyes to prevent desiccation of the cornea.

We aged deer by tooth wear and replacement (Severinghaus 1949) and fitted each deer with an ear tag (Global Super Maxi, Allflex® USA, Inc., Dallas – Forth Worth Airport, Texas) and a global positioning system (GPS) collar (GPS Budget, TVP Positioning AB, Lindesberg, Sweden).

We reversed the effects of Rompun with an intravenous 3.0 mg/kg injection of tolazoline hydrochloride (Tolazine®; Lloyd, Inc., Shenandoah, Iowa). Contact names and phone numbers were clearly placed on each identification item; both ear tags and GPS collars were labeled to identify captured deer and advise consumption by humans. Deer captured on the Farm were temporarily marked with high-visibility water-based paint along the front shoulder, rib cage, and flank to prevent hunter harvest of study animals.

GPS collars were programmed to gather coordinates of each deer's location hourly through the breeding season (15 November 2004 – 30 January 2005). To preserve battery life, coordinates were recorded once every 2 h from 31 January 2005 to 27 February 2005. Televilt Budget GPS collars are reported accurate to ±15 m for 90% of 3D fixes. We felt that this small amount of error was insignificant for the purposes of this research.

Uncollared Park deer ($n = 215$) were removed via sharpshooting from a vehicle or tree stands from 3 January to 9 January 2005, reducing deer density from 83 to 7 deer/km². Free-ranging deer on the Farm were subjected to a series of intensive controlled shotgun hunts utilizing licensed hunters on 23–24 November, 6–11 December, and 15–17 December 2004, during which time 392 deer were removed and thereby reducing density from 78 to 27 deer/km².

Study animals were captured and collared throughout the property (both Park and Farm) to increase probabilities that they were part of different matrilineal groups. We did not capture animals from a group visually associating with a previously collared deer. While there may have been some relatedness between research animals, care was taken to minimize the impacts of family subunits on resulting behavioral changes.

Deer capture and sharpshooting were conducted by White Buffalo, Inc. under the authority of the State of New Jersey, Department of Environmental Protection, Division of Fish and Wildlife in accordance with the Canadian Council on Animal Care's *Guide to the Care and Use of Experimental Animals*. An Institutional Animal Care and Use Committee permit exemption was issued by the University of Connecticut (permit no. E05113), as the only University involvement in this project were data analysis and research.

Data management and analyses

We downloaded spatial data from GPS collars, imported them into Microsoft Excel 2003, and then into the geographic information system program ArcView version 3.3 (Environmental Systems Research Institute Inc., Redlands, California). Data were overlain on standard digital 7.5 ft (1 ft = 0.3048 m) USGS topographic maps and digital orthophotos. Raw GPS output data were used, though obviously impossible data points (data points >10 km from the preceding hourly point) were removed based on visual inspection in ArcView. Weekly home ranges and core areas were calculated using the adaptive kernel method (Worton 1989) within the Animal Movement extension (version 1.1) of ArcView (Hooge and Eichenlaub 1997). Home ranges were estimated using the 95% confidence interval to minimize the effect of outliers, leading to a more precise definition of home range. Core activity areas were calculated using the 50% confidence interval. Home range and core areas were

calculated weekly for Park deer for each of the 6 weeks preshoot, during the week of the sharpshoot, and for each of the 7 weeks postshoot (weekly from 22 November 2004 to 27 February 2005). Home range and core areas for Farm deer were estimated weekly for the same intervals for comparison. Two-way analysis of variance (ANOVA) controlling for sex of animals and interval was used when comparing differences within herds over time. No less than 30 data points were used for any individual for kernel range estimation (Seaman et al. 1999).

In addition, daily home ranges of all deer were estimated using minimum convex polygon (MCP) within the Animal Movement extension of ArcView for each day of the 6 week interval encompassing lethal removal efforts for both the Farm (20 November – 31 December 2004) and Park (27 December 2004 – 6 February 2005) herds. Minimum convex polygon was used as the home-range estimator in these instances as hourly coordinate data (maximum 24/day) precluded the use of kernel estimation owing to the minimum number of points ($n = 30$) not being obtained (Seaman et al. 1999).

The intersection of overlapping MCP ranges was calculated in ArcView for all animal combinations by sex (doe–doe, buck–buck, buck–doe) both within the Park ($n = 153$) and the Farm ($n = 88$) for each day of the 6 week intervals. Buck–buck interactions were not calculated for the Farm herd because of the low number of bucks ($n = 3$) for which collar data were obtained for this analysis. An overlap index (OI) was calculated by modification of a formula presented by Chamberlain and Leopold (2002): $OI = [(n_{1,2} \times 2)/(N_1 + N_2)] \times 100$, where $n_{1,2}$ refers to the shared area (ha) of overlap for a deer pair and N_1 and N_2 refer to the area of the MCP range (ha) for each animal in the overlapping pair.

The controlled hunts on the Farm were of varying duration, as were times between hunts. Therefore, OI values were summed for each pair combination for hunting and nonhunting intervals and divided by the number of days in each respective interval to give mean daily OI values. Park deer OI values were summed for all combination of animals weekly for the 1 week preshoot, the week of the shoot itself, and for each of the 4 weeks postshoot. Each weekly sum was averaged to give mean daily OI values to remain consistent with the Farm analysis. One-way ANOVA was used to test differences in OI values for interactions within each herd. Pairwise multiple comparisons were made using Bonferroni adjustment.

To assess core-area shifting as a result of density reduction, core-area centroids were calculated within ArcView for Park animals. Distances were measured from the 50% adaptive kernel core-area centroid for the preshoot week (before animals were manipulated) to core-area centroids for the shoot and each of the remaining 4 weeks postshoot for all animals. Data were only available for eight does and seven bucks within the Park for this analysis. This analysis could not be run for the Farm herd, as there were no prehunt data available to establish baseline home ranges. Two-way ANOVA was used to test for differences in the distances between core-area centroids by week and by sex. SYSTAT version 7.0 (SPSS, Inc., Chicago, IL, USA) was used for all statistical analyses.

Fig. 1. Mean weekly home ranges (95%) and standard error of the mean error bars of Park white-tailed deer (*Odocoileus virginianus*) for weeks around the sharpshoot (indicated by the arrow).
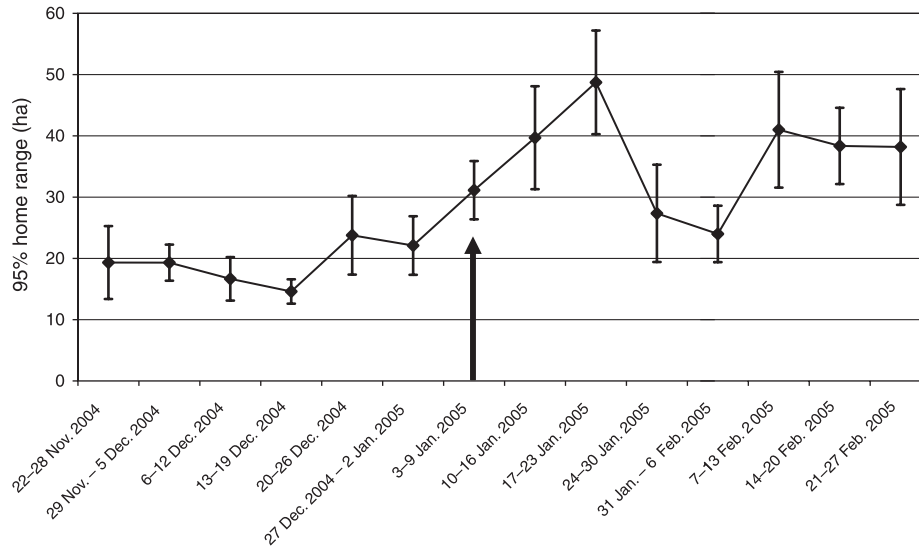
Results

We deployed GPS collars on 47 individual animals. Collars from animals that died during the study from vehicle collisions, predation, or other causes were removed and placed on additional animals as battery life permitted. Collars were recovered and data were downloaded from 45 individual deer; two collars on Farm bucks were not recovered. Locational data were used in each analysis for only those animals for which data were collected during the appropriate time interval (Park = 11 females, 7 males; Farm = 11 females, 3 males).

Mean home ranges

Mean weekly kernel home-range size for Park deer was 19.4 ha (SE = 1.9) for the 6 weeks preshoot and 36.7 ha (SE = 3.0) for the 7 weeks postshoot. Mean weekly home range increased to a high of 48.7 ha (SE = 8.5) during the interval 2 weeks postshoot (Fig. 1). Mean weekly ranges differed ($F_{[13,200]} = 2.3$, $p < 0.01$), though neither the sex of the animal ($F_{[1,200]} = 3.6$, $p = 0.06$) nor the interaction between sex and interval ($F_{[13,200]} = 0.6$, $p = 0.86$) was a factor. Weekly core areas averaged 2.5 ha (SE = 0.3) preshoot and 5.0 ha (SE = 0.4) postshoot. Differences between core areas were significant ($F_{[13,200]} = 2.2$, $p = 0.01$), though sex ($F_{[1,200]} = 1.62$, $p = 0.21$) and the interaction between sex and interval ($F_{[13,200]} = 0.5$, $p = 0.92$) did not differ. Weekly home ranges and core areas were estimated using a mean 99 data points/animal.

Mean weekly kernel home-range size for Farm deer was 116.6 ha (SE = 11.9) for the 6 week interval corresponding to the Park preshoot interval and 68.9 ha (SE = 4.9) for the corresponding 7 week postshoot interval. All controlled hunting activities occurred during the interval corresponding to the 6 week presharpshoot interval. Mean weekly home range was highest (mean = 220.2 ha, SE = 51.1) during the week that included the 6 day hunt (6–11 December 2004) (Fig. 2). Mean weekly kernel home ranges differed ($F_{[13,163]} = 3.9$, $p < 0.01$), though neither the sex of the animal ($F_{[1,163]} = 0.2$, $p = 0.65$) nor the interaction between the two ($F_{[13,163]} = 0.7$, $p = 0.74$) differed. Mean weekly core areas averaged 17.4 ha (SE = 2.0) for the 6 week preshoot interval and 10.4 ha (SE = 0.9) for the 7 week postshoot interval. Mean core-area sizes differed for Farm deer ($F_{[13,163]} = 2.5$, $p < 0.01$), though neither the sex ($F_{[1,163]} = 0.5$, $p = 0.47$) nor the interaction between sex and interval ($F_{[13,163]} = 0.7$, $p = 0.80$) was a factor. Weekly home ranges and core areas were estimated using a mean 105 data points/animal.

Social interactions and core-area shifts

Mean daily OI differed for doe–doe ($F_{[5,297]} = 3.2$, $p < 0.01$) and buck–doe ($F_{[5,438]} = 2.3$, $p < 0.05$) interactions for the Park herd only (Fig. 3). Does had higher mean OI values postshoot. There were no differences in buck–buck home-range overlap in the Park ($F_{[5,120]} = 0.6$, $p = 0.72$) (Fig. 3); there were also no differences in doe–doe ($F_{[5,324]} = 1.1$, $p = 0.37$) or buck–doe ($F_{[5,192]} = 1.0$, $p = 0.42$) home-range overlap for the Farm (Fig. 4). Daily MCP ranges were estimated using a mean 15 data points/day for Park animals and 16 data points/day for Farm animals.

Distances between baseline core-area centroids 1 week preshoot to the week of the sharpshoot and the remaining 4 weeks postshoot continually increased, but because of the high variability, were not significantly different by week ($F_{[4,65]} = 1.5$, $p = 0.22$), sex ($F_{[1,65]} = 3.8$, $p = 0.06$), or their interaction ($F_{[4,65]} = 0.2$, $p = 0.93$) (Table 1).

Discussion

Controlled hunting using licensed hunters has long been a management tool for reducing overabundant deer herds in localized areas (Roseberry et al. 1969; Kilpatrick et al. 1997, 2002; Doerr et al. 2001). Managers and organizers of controlled hunts often use numerous participants to attempt to reduce deer population sizes in localized areas by effectively oversaturating the area with hunters, in some cases, 1 hunter/0.85 ha (Kilpatrick et al. 2002). While this modern

Fig. 2. Mean weekly home ranges (95%) and standard error of the mean error bars of Farm white-tailed deer (*Odocoileus virginianus*), which encompass hunt dates (indicated by the arrows).
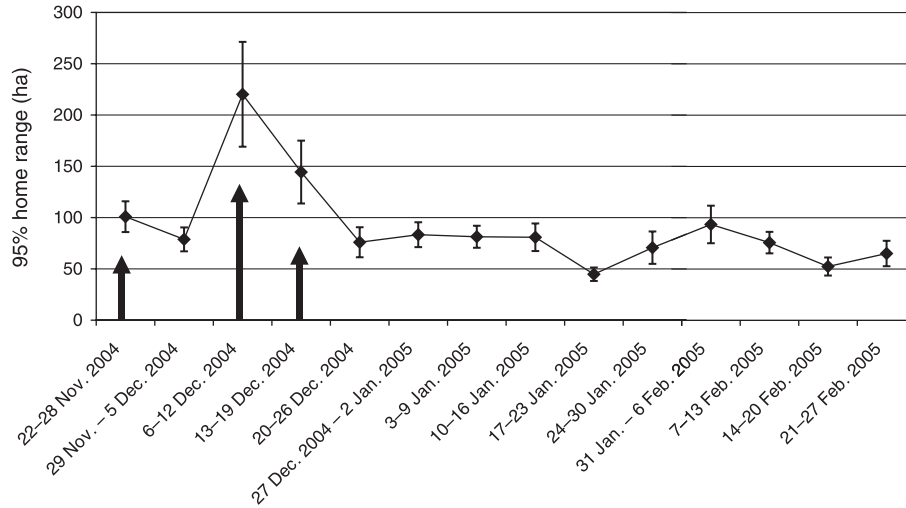
Fig. 3. Mean overlap index values by week for doe–doe and buck–doe interactions for the Park white-tailed deer (*Odocoileus virginianus*) herd. Means with the same letter are not significantly different within each series. Sharpshooting week indicated by the arrow.
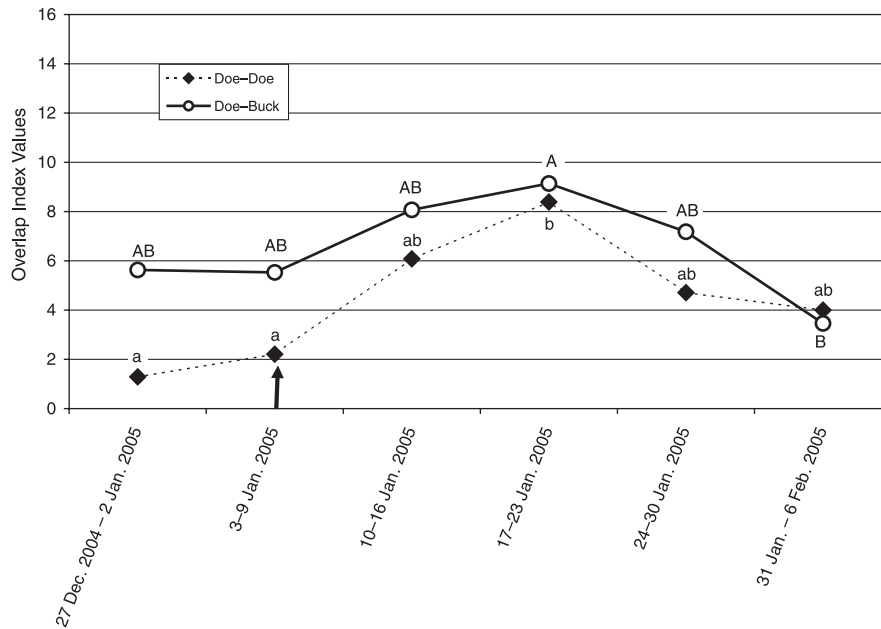
strategy is effective at providing recreational opportunities for the public, it may have limited effectiveness in reducing deer population numbers to ecologically desirable levels on large parcels with proximate refugia (Brown et al. 2000; Storm et al. 2007).

Farm deer exhibited an increase in mean home-range size during periods of hunting and a reduction in home-range size in the absence of hunting. White-tailed deer exhibit such behavioral modifications to seek refuge when hunters are present (Kilgo et al. 1998; Root et al. 1988; Kilpatrick et al. 2002). Kilgo et al. (1998) documented that female white-tailed deer in Florida were found farther from roads, increased nocturnal activity, and preferred swamps and mature pine stands during periods of hunting compared with periods of nonhunting. Kilpatrick et al. (2002) suggested that dense patches of cover served as refugia for deer subjected to controlled hunting in Connecticut and also sug-

gested that deer are quickly educated to hunter presence. In addition, deer in hunted populations are more mobile than in unhunted populations (Root et al. 1988).

Sharpshooting does not provide recreational opportunities and direct costs can be expensive, but rival or may be lower than controlled hunts owing to intensive state agency involvement (DeNicola et al. 1997). However, results from sharpshoots are effective and immediate. Controlled hunting is currently the best option for managers with minimal resources at their disposal, but we feel that the ability to achieve and maintain acceptable population reductions lies in the learning potential and resulting behaviors of white-tailed deer.

Park animals were removed in a systematic manner, with relaxed restrictions on take. Animals were harvested at night, over bait, from tree stands, or a vehicle: sharpshooters had more control over removal efforts. Only shots that

Fig. 4. Mean overlap index values by week for doe–doe and buck–doe interactions for the Farm white-tailed deer (*Odocoileus virginianus*) herd. Means with the same letter are not significantly different within each series. Hunting intervals indicated by the arrows.
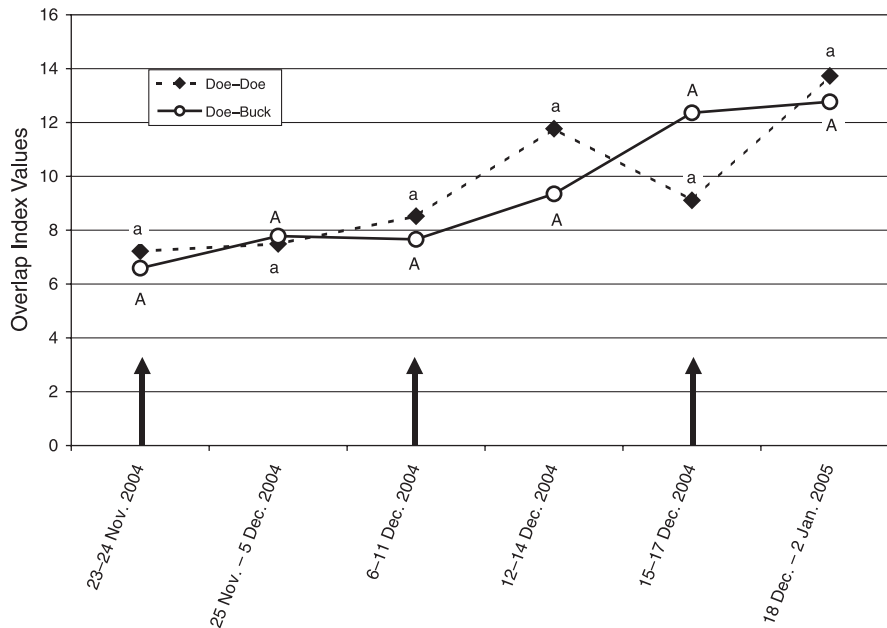
Table 1. Mean distances (m) from kernel core-area centroids for Park white-tailed deer (*Odocoileus virginianus*) from the baseline core area 1 week preshoot to weekly kernel core-area centroids during the shoot (Shoot) and each of the 4 weeks postshoot (1–4 post).

	Buck		Doe		Combined	
	Mean	SE	Mean	SE	Mean	SE
Shoot	268.8	73.7	153.6	38.3	194.5	41.4
1 post	292.9	84.1	271.0	86.1	263.7	58.3
2 post	438.6	126.2	239.2	76.4	311.6	73.8
3 post	465.3	146.8	327.2	80.4	367.3	79.8
4 post	484.8	125.2	351.9	117.7	388.1	84.5

would insure a clean kill were made with care not to educate other animals that may witness the harvest. Large herds were allowed to dissipate before any animals were harvested so that unharvested animals would remain naïve for harvest at a later time. The limited range expansion during Park removal efforts and the fact that mean home ranges peaked postshoot demonstrates that deer behaviors were disrupted less by sharpshooting.

While home-range expansion itself may not necessarily be a harvest avoidance strategy, we believe the dramatic range increase occurred as Farm animals sought refuge from hunters on unhuntable portions of adjacent properties. Though Park habitat differed somewhat, we believe that the same range expansion was not witnessed during removal efforts because of the differences in harvest strategy, as sharpshooters were much less disruptive than controlled hunting. A particularly interesting and unexpected result was why Park animals showed a significant increase in mean home-range size postshoot, while Farm animals maintained a relatively consistent mean home-range size posthunt.

Sociality

Female white-tailed deer establish home ranges adjacent to, and often overlapping, with that of the dam, while male offspring disperse to unfamiliar areas to establish new home ranges (Hawkins and Klimstra 1970; Hawkins et al. 1971; Tierson et al. 1985; Rosenberry et al. 2001). Females account for a high proportion of the population (62% of Park animals) because dispersing males experience higher mortality rates (Rosenberry et al. 2001). Social interactions between females are of interest from a management perspective because behaviors can be learned through successive generations (Tierson et al. 1985; Williams and DeNicola 2002).

White-tailed deer exhibit high home-range site fidelity (Marchinton and Hirth 1984). Deer were reported to starve to death rather than shift ranges to adjacent areas with available forage (Severinghaus and Cheatum 1956; Thomas et al. 1964). Similarly, deer may not invade voids created by population reductions in areas adjacent to established home ranges (Behrend et al. 1970; Tierson et al. 1985; McNulty et al. 1997; Williams and DeNicola 2002). Some research suggests that deer will remain in established home ranges during periods of hunting (Marshall and Whittington 1968; Kufeld et al. 1988). However, others report home-range expansion and fleeing beyond known ranges (Van Etten et al. 1965; Root et al. 1988; VerCauteren and Hygnstrom 1998). Such conflicting reports are likely due to varying hunting intensities, deer population densities, and habitat type.

We suspected that Park deer increased home-range sizes postshoot while attempting to restructure their social network. Remaining Park research deer were effectively isolated from other individuals through the removal of social counterparts, as more than 91% of the population was removed over 7 days. Differences in MCP OI values existed postshoot for Park doe–doe interactions. Differences also existed for doe–buck interactions, but this phenomenon was

likely driven by doe sociality and the larger home-range sizes of bucks. Similar spatial data did not suggest changes social behaviors of Farm deer. This could be due to a variety of factors: that the Farm population was not reduced enough to elicit such behavioral changes, that some matrilineal social groups remained intact, that animals socializing with collared animals had a better chance of survival since hunters were instructed not to harvest study animals, or a combination of the three.

We suspect that we witnessed a social regrouping of Park deer owing to the loss of matrilineal counterparts. This suggests that the social nature of white-tailed deer can override the innate survival mechanism of high home-range site fidelity. We argue that white-tailed deer may rely more on their social network for survival purposes than previously thought. We also suggest that home-range site fidelity in white-tailed deer is a function of both the intimate knowledge of home range and the adjacent matrilineal network. While our data immediately after the sharpshoot did not statistically support our hypothesis, we believe that over time, and in the absence of an intact social network, females previously at high density will abandon known ranges to associate with unrelated individuals. This suspicion could be confirmed if GPS collar battery life could be improved to take intensive readings over an increased period of time.

Management implications

Proper management of overabundant deer herds should persist on an annual basis to increase mortality to achieve negative population growth (see DeNicola and Williams 2008). However, lack of funding, as well as social and political pressures, may limit such sustained efforts. In these instances, one-time large-scale controlled hunts often occur. Such coordinated hunts can temporarily reduce population numbers, but also rapidly educate remaining animals, hampering future management efforts of targeted populations. Where controlled hunting can be used in annual sustained efforts, managers need to focus their efforts on hunter behavior rather than deer behavior. Minimally, managers need to conduct thorough interviews with hunters, use shooting proficiency tests, and educate hunters when to best harvest an animal given its proximity to others. Unfortunately, these tactics have been used in the past with limited success. One additional suggestion is an ammunition restriction (2–3 rounds/valid tag) during controlled hunts that would force participants to take clean-shot opportunities, would educate fewer animals, and would likely increase harvest over the duration of the hunting program. Regardless of which strategy is used, managers need to take into account the impact of density reduction on postharvest behaviors when formulating management plans.

Acknowledgements

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