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Original Article

Evaluation of Organized Hunting as a Management Technique for Overabundant White-Tailed Deer in Suburban Landscapes

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ABSTRACT Hunting has been the primary white-tailed deer (*Odocoileus virginianus*) management tool for decades. Regulated hunting has been effective at meeting management objectives in rural areas, but typical logistical constraints placed on hunting in residential and urban areas can cause deer to become overabundant and incompatible with other societal interests. Deer–vehicle collisions, tick-associated diseases, and damage to residential landscape plantings are the primary reasons for implementing lethal management programs, often with objectives of <10 deer/km^2. There are limited data demonstrating that hunting alone in suburban landscapes can reduce densities sufficiently to result in adequate conflict resolutions or a corresponding density objective for deer. We present data from 3 controlled hunting programs in New Jersey and one in Pennsylvania, USA. Annual or periodic population estimates were conducted using aerial counts and road-based distance sampling to assess trends. Initial populations, some of which were previously subjected to regulated unorganized hunting, ranged from approximately 30–80 deer/km^2. From 3 years to 10 years of traditional hunting, along with organized hunting and liberalized regulations, resulted in an estimated 17–18 deer/km^2 at each location. These projects clearly demonstrate that a reduction in local deer densities using regulated hunting can be achieved. However, the sole use of existing regulated hunting techniques in suburban areas appears insufficient to maintain deer densities <17 deer/km^2 where deer are not limited by severe winter weather. Additional measures, such as sharpshooting or other strategic adjustments to regulations and policies, may be needed if long-term deer-management objectives are much below this level.

KEY WORDS archery, deer–vehicle collisions, human–wildlife conflicts, hunting, *Odocoileus virginianus*, sharpshooting, suburban, white-tailed deer, wildlife damage management.

The most significant conflicts that arise when white-tailed deer (*Odocoileus virginianus*) become overabundant in suburban environments are concerns of increased risk of tick-borne infections, particularly Lyme disease (Stafford 2007), deer–vehicle collisions (DVCs; DeNicola and Williams 2008), and repeated damage to residential landscape plantings (DeNicola et al. 2000). Additionally, impacts of elevated deer densities on plant diversity and forest regeneration are well-documented and of serious concern to ecologists and biologists (Alverson et al. 1988, Frankland and Nelson 2003, Horsley et al. 2003, Carson et al. 2005). There is a positive correlation between white-tailed deer and black-legged tick (*Ixodes scapularis*) abundances and associated risks of contracting Lyme disease and other tick-borne pathogens (Stafford 1993; Stafford et al. 2003; Rand et al. 2003, 2004). There are >1,000,000 DVCs estimated to occur in the United States annually and >200 human deaths attributed to these events (Conover et al. 1995, Luedke 2011). Earlier studies reported that DVCs increased as local deer populations increased (Hygnstrom and VerCauteren 1999, Etter et al. 2000), and another reported that a reduction in deer abundance resulted in a corresponding decline in DVCs (DeNicola and Williams 2008).

The only way to efficiently and effectively reduce deer abundance is through removal of deer from a local population (DeNicola et al. 2000, Rutberg et al. 2004). In most states, live-trapping and relocation is not an option because of high costs, pathogen transmission risks (e.g., chronic wasting disease), unavailability of suitable release sites, and concerns over stress to captured deer. Furthermore, most relocated deer do not survive a year in their new environments (Conover 2002). Therefore, only lethal management options (i.e., hunting, sharpshooting, and live-capture followed by euthanasia) can potentially reduce deer densities in the short term.

Hunting is often recommended in suburban communities to address conflicts associated with overabundant deer, and as

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a result, many communities and parks have used managed hunts to control deer numbers (Deblinger et al. 1995, Hansen and Beringer 1997, Kilpatrick et al. 2002). Several case studies have documented the challenges of managing deer in developed settings. Archery hunting was effective and safe on a small scale, but antlerless harvest had to be repeatedly emphasized, and intensive wildlife agency involvement was necessary to meet management goals (Kilpatrick and Walter 1999, Kilpatrick et al. 2004). Following the implementation of a coordinated hunting program in developed suburban environments, there are few examples that document population reductions that have sufficiently met community or landowner goals. The inability to reduce densities of deer to meet management objectives can be particularly true when communities desire long-term reductions to address ecological damage and Lyme disease concerns, typically to about 8 deer/km^2 (Rand et al. 2003, Stafford 2007).

In most cases, hunters have limited access, legal restrictions (i.e., firearm discharge limitations), or may not prefer to see deer densities reduced below a level of recreational interest (Storm et al. 2007, Weckel et al. 2011). Given that most hunters are only interested in harvesting about one antlerless deer annually (Riley et al. 2003), there is some concern whether hunters can meet management goals even if access is not limited. For instance, in 4 ecoregions of New York, USA, if hunters in an unlimited tagging system filled as many antlerless tags as they predicted, they would exceed harvest levels needed to stabilize the population in one ecoregion, equal needed harvest in another, and be below needed harvest in the other two (Brown et al. 2000). Therefore, there is some doubt about the actual population impact hunters can have in many suburban and urban environments.

Currently, the most effective mechanism for controlling overabundant white-tailed deer is lethal removal and most commonly, controlled firearm-hunting and sharpshooting. Sharpshooting was used to reduce a herd in a community in Minnesota, USA; it was reported to have the highest kill rate, and was the most adaptable method in urban scenarios (Doerr et al. 2001). Sharpshooting techniques were used to extirpate deer from the 237-ha Monhegan Island, Maine, USA (Rand et al. 2004). Sharpshooting has also been used successfully to reduce deer abundances in many other instances (Drummond 1995, Jordan et al. 1995, Stradtmann et al. 1995, Curtis et al. 1997). Archery hunting may be ineffective at reducing deer densities to low levels because many deer learn of the threat of humans during a prolonged harvest season (Kilpatrick and Lima 1999). Deer subjected to such efforts become educated and may behave differently during removal, and surviving deer may alter behaviors, potentially limiting efficacy of future removal efforts (Williams et al. 2008). There appears to be a threshold where hunters can no longer reduce deer densities because deer become too elusive and diminishing returns keep hunters from putting forth additional effort, as seen in many states where late-season (post-Jan 1) harvest totals are typically <10% of total (Anonymous 2011, Kilpatrick et al. 2011).

Our objective was to determine the deer population management potential of modern traditional hunting under extremely liberal state regulations and hunting opportunities in areas of the mid-coastal eastern United States with initial deer overabundance ($\geq$35 deer/km^2). We present 4 case studies to demonstrate the relative effectiveness of regulated hunting in reducing deer densities to levels consistent with community goals regarding public concerns about tick-borne illnesses, ecosystem health, and DVCs.

STUDY AREAS

Princeton Township (Princeton), New Jersey, USA (40.348722°, −74.659029°) was in Mercer County and had a human population of 16,265 during the 2010 Census. Unorganized hunting, using all regulated hunting seasons, occurred from the late 1980s through the present. The incidence of DVCs had grown to unacceptable levels (Anonymous 1998), and therefore controlled archery hunts were implemented on both private and public properties beginning in autumn 2006 through late winter 2011. Additionally, supplemental sharpshooting and live-capture with euthanasia was implemented after hunting seasons from 2001 through 2010. Management efforts occurred throughout the majority of Princeton Township (36.3 km^2).

Bernards Township (Bernards), New Jersey (40.718846°, −74.568659°) was in Somerset County and had a human population of 26,652 during the 2010 Census. Because of increased DVCs and intolerable damage to gardens and landscape plantings (Anonymous 2009), the Township repeatedly sought and received a Community-Based Deer Management Permit from the New Jersey Department of Environmental Protection that extended the hunting season an additional 4 weeks. In addition to the post-season permit, coordinated deer-management efforts occurred throughout Bernards (63.5 km^2) on both public and private lands during the 4.5-month autumn–winter archery-hunting seasons from autumn 2001 through 2011.

Upper Makefield Township (Upper Makefield), Pennsylvania, USA (40.291944°, −74.924167°) was a suburb of Philadelphia in Bucks County and had a human population of 8,190 during the 2010 Census. Because of increased DVCs, landscape damage, and concerns about tick-borne diseases, a private firm was hired to conduct a coordinated deer-management effort, using archery hunting, on up to 92 private properties throughout Upper Makefield (51.8 km^2; Maddock et al. 2009). Management efforts started in autumn 2007 and ended late winter 2010.

These 3 communities were typical suburban landscapes for the area, composed of a matrix of residential and commercial developments, with intermingled wetlands, woodlands, and agricultural lands. They were almost exclusively single-family residential communities with property sizes ranging from 0.4 ha to 2.0 ha with some properties >8 ha. Hunting access was limited to properties with written permission, and as a result, numerous non-hunted refugia were available to deer.

Duke Farms was a 1,110-ha tract located in Hillsborough, New Jersey (40.554896°, −74.634247°). The property was a mix of natural habitat types as well as a 259-ha designed park that was surrounded by a 2.5-m deer exclusion fence. The habitat types included 445 ha of agricultural grasslands, 422 ha of woodlands, 214 ha of floodplain, and 29 ha of open water. This mix of habitat types provided wildlife refuge, as Duke Farms was surrounded by industrial areas to the south, commercial properties and residential developments to the east and west, and the Raritan River to the north. A portion of the property was designated by the New Jersey Department of Environmental Protection as part of the Orchard Drive Grasslands Natural Heritage Priority Site, which was considered one of the state's most significant natural areas. Due to increasing DVCs and chronic damage to forest understory and ornamental plantings, management efforts were conducted at Duke Farms during autumn–winter beginning in 2004 through 2011. Management activities, using both archery and shotgun hunting, were focused on the 800-ha unfenced area of Duke Farms.

The management goals of Princeton, Bernards, and Duke Farms were to reduce deer densities to $\leq$10 deer/km^2. Upper Makefield did not have a specific goal except to reduce DVCs and other local conflicts (T. Waterbury [Princeton Township attorney], W. Allen [Chair, Bernards Township Deer Management Advisory Committee], G. Huntington [Duke Farms Foundation] personal communications; Maddock et al. 2009).

METHODS

Deer Removal

All sites had extended archery seasons (4–5 months), and hunters could use bait to attract deer. All hunters were tested for shooting proficiency to various degrees and attended local orientations. Successful hunters were issued replacement tags, so they could potentially remove an unlimited number of antlerless deer. The 3 communities and Duke Farms used the following approaches to try to meet their management objectives: 1) maximal access to huntable property, 2) full cooperation of the township administration and its residents, 3) proper screening of the participating hunters, and 4) close management of hunters' actions and locations.

Princeton used select archers on public and private lands and sharpshooting and live-capture with euthanasia after the archery hunt (DeNicola et al. 1997). Participating archers had access to 4 public properties in 2006 and 2007, 5 public properties in 2008 and 2009, and 8 public and 5 private properties in 2010. Non-participating hunters had the opportunity to obtain access and hunt any private property during all regulated hunting seasons in Princeton. The local animal-control officer was responsible for oversight of proficiency testing and daily hunter activities. Deer densities were reduced with sharpshooting after the hunting seasons from 2001 to 2009. In 2010–2011, Princeton only permitted archery hunting and opted not to sharpshoot.

Bernards Township hired a small group of shotgun hunters in 2002, but results were limited and expensive and, therefore, lasted only 1 year (Snyder and Allen 2011). Concurrently, a group of 15 archers were used to kill deer. Additionally, in 2003, another organization consisting of 39 hunters using archery, shotguns, and muzzleloaders participated. The 2 groups hunted throughout the township through 2010–2011. Local law-enforcement department personnel were responsible for oversight of proficiency testing and daily hunter activities. Harvest data were not differentiated between archery, shotgun, or muzzleloader, but organizers estimated half of all deer were taken with archery (W. Allen, Chair, Bernards Township Deer Management Advisory Committee, personal communication).

Upper Makefield used 27 archery participants on 65 private lands in Year 1, 35 archers on 81 properties in Year 2, and 39 archers on 92 properties in Year 3. A private wildlife management company (Eccologix, Inc., Bedminster, PA) was responsible for obtaining access to private properties, oversight of screening of hunters, proficiency testing, and daily hunter activities at a cost of approximately US$55,000/year.

Duke Farms used a combination of both archery- and shotgun-hunting. The first year (2004–2005), over 70 participants used only shotguns. Each hunter was placed in an approximate 2-ha designated area to ensure complete coverage of all wooded areas to prevent deer refuge (Williams et al. 2008). During shotgun hunting, groups of >100 deer were observed congregating in the center of large fields (>100 ha; A. J. DeNicola, personal observation). Deer seeking refuge were dispersed to hunters in tree stands by non-hunting participants on foot or in off-road vehicles to increase the likelihood of harvest. In each subsequent year, archery- and shotgun-hunting were used (12–33 participants) with no shotgun-hunting occurring in 2005–2006 and 2008–2009. A private wildlife management company (White Buffalo, Inc., Moodus, CT) was responsible for initial oversight of screening and proficiency testing and daily hunter activities. Duke Farms' staff allocated hundreds of hours to subsequent program management and paid for bait and carcass donation. To assess the effectiveness of dispersing deer from non-hunted refugia to hunters after the first year, the number of deer harvested from such efforts was added to the end of year forward-looking-infrared counts and densities were recalculated. This calculation assumes that none of the deer harvested during dispersal efforts would have been taken by a sitting hunter, so it is likely an overestimate.

Density and Abundance Estimation

Deer density and abundance in Upper Makefield and Princeton were estimated using road-based distance sampling (LaRue et al. 2007) in March 2010 and February 2011, respectively. Distinct clusters were determined using the nearest-neighbor criterion and by observing behavior and proximity of individuals (LaGory 1986). Routes were surveyed for 3 consecutive nights to ensure $\geq$60 deer clusters were recorded (Buckland et al. 1993). We used the Program DISTANCE 4.0 to estimate deer density near roads (Thomas et al. 2002). We used recommended protocols for analysis of line-transect data (Buckland et al. 1993:139–140).

Population estimates were derived using forward-looking-infrared techniques (Naugle et al. 1996) annually at Duke Farms and twice at Bernards. Aerial infrared counts were conducted using a single-engine Cessna 182 with a fuselage-mounted high-resolution Mitsubishi M-600 thermal imager

(Mitsubishi Electric, Irvine, CA). Transects were spaced at 100-m intervals and flown 500 m above ground. At this height above ground, 100% coverage was achieved and verified with global positioning system moving map software. Flights were conducted after 2200 hours to ensure adequate ground cooling and good thermal contrast. The thermal imaging output was routed through a video encoder-decoder (Model VED-M, V-data, Inc., Lottsburg, VA) and recorded on digital media for later review. From previous experience, forward-looking-infrared counts that do not estimate imperfect detection rates result in an underestimate of deer abundance, so actual reported densities at Duke Farms and Bernards are likely to be conservative (Drake et al. 2005).

Understanding that raw count data can provide unreliable indices (Anderson 2001), we used multiple lines of evidence to assess deer population densities and trends. Population estimates, including initial population estimates, were corroborated by conducting simple population projections based on observed demographics (DeNicola et al. 2008). We estimated that 1) 60% of the populations were female, 2) 33% of females were fawns, and 3) recruitment rate to autumn was 1:1 (doe:fawn ratio). We then included approximations of non-culling mortality (i.e., DVC data and hunter-harvest data when available), and approximate mortality rates for urban deer from the literature to estimate pre-hunt densities (Etter et al. 2002). Immigration and emigration were assumed to be equal because deer typically do not shift established home ranges into areas of lower density (McNulty et al. 1997, Williams and DeNicola 2002) or even to accommodate temporary bait sites (Williams and DeNicola 2000, Kilpatrick and Stober 2002).

We estimated population size of deer at Princeton using an aerial count in winter 2002 with snow cover. We attempted to correct for imperfect detection of deer by using a double-observer method (Beringer et al. 1998, Potvin and Breton 2005). We used a Robinson 44 helicopter (Robinson Helicopter Company, Torrance, CA) with a pilot and experienced observers on both sides of the aircraft. We flew 200-m-wide transects that were pre-established in the geographic-information-system program ArcView (version 3.3). We provided the pilot with starting and ending global positioning system coordinates of each transect prior to the survey. Once airborne, the pilot hovered at an altitude of 60 m, at which time observers placed a piece of tape on the window, which corresponded to orange traffic cones on the ground 100 m to the side of the aircraft. Observers maintained this search distance throughout the survey while the pilot maintained an altitude of 60 m and air speed of 40 km/hour, though altitude and air speed varied somewhat throughout the flights. When deer were sighted, their numbers and location were recorded on a topographic map. Based on previous research, we assumed that 2 experienced observers had an 80% detection function and adjusted the data accordingly (Beringer et al. 1998). Aerial surveys may be a more reliable technique to estimate deer population size compared with distance sampling from roads (Naugle et al. 1996), but financial limitations precluded another aerial survey of Princeton in 2011.

We realize that there are inherent complexities in deer density estimation and that there may be some variation between techniques due to differing calculations, observer bias, or animal behaviors such as habituation to human-altered landscapes (Haskell et al. 2009). Although we cannot say how accurate our surveys were, we are confident in our ability to assess broad-scale population objectives over time.

Deer–Vehicle Collisions

Deer–vehicle collisions were tallied through a combination of police reports and roadkill collection records by animal control officers or private contractors. Data collection methods were consistent among years at all locations.

Data Analyses

We used linear regression to determine whether estimated densities for each study area had been significantly reduced over time (SigmaPlot 12.0). We also categorized the pre-hunt density estimates of deer by Years 0–3 and Years 3–11 to analyze similarly.

RESULTS

Deer Removal and Density and Abundance Estimation

A total of 10,525 deer were documented as being removed from the 4 areas over the study period with 1) 4,785 (45%) removed by archery hunting, 2) 3,224 (31%) removed by shotgun or muzzleloader hunting, 3) 314 (3%) were not differentiated as being taken by either archery or shotgun, and 4) 2,202 (21%) removed by sharpshooting (Table 1). An additional 3,527 deer were documented as being killed by DVCs.

Princeton Township

The initial (pre-2001) population estimate exceeded 43 deer/km^2. Over the 11-year program, 4,563 deer were reported taken by sharpshooting, DVCs, or archery hunting.

Table 1. White-tailed deer (*Odocoileus virginianus*) harvest totals for the 4 study areas (Upper Makefield Township, Pennsylvania, USA from 2007 to 2010, Bernards Township, New Jersey, USA from 2000 to 2011, Princeton Township, New Jersey, USA from 2000 to 2011, and Duke Farms, New Jersey, USA from 2004 to 2011) by method of take. Densities are reported as number of deer per km^2.

	Seasons	Archery	Gun	ND	S.S.	Initial den.	Final den.
Upper Makefield	3	828	61	314	188	≈35	≈18
Bernards Township	11	2,602	2,603	—	N/A	≈34[a]	≈18
Princeton Township	11	1,077	N/A	—	1,986	≈43	≈17
Duke Farms	7	278	560	—	28	≈80	≈12
Totals	32	4,785	3,224	314	2,202		

ND, not differentiated between archery and shotgun; S.S., sharpshooting, N/A, not attempted.
[a] Initial density was determined after 1 year of limited coordinated hunting.

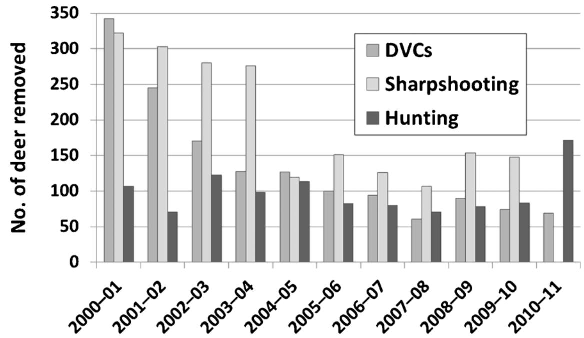

Figure 1. White-tailed deer (*Odocoileus virginianus*) harvest totals for coordinated removal efforts in Princeton Township, New Jersey, USA, from 2000 to 2011. DVCs, deer–vehicle collisions.

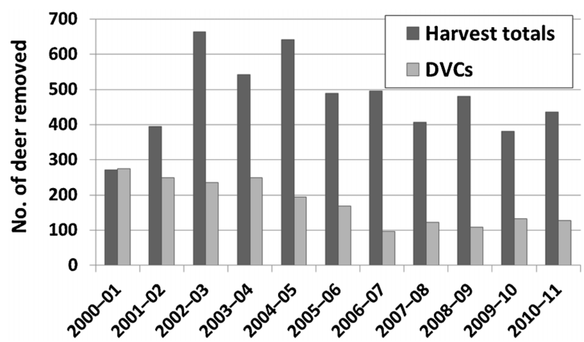

Figure 2. White-tailed deer (*Odocoileus virginianus*) harvest totals for coordinated removal efforts in Bernards Township, New Jersey, USA, from 2000 to 2011. "Harvest totals" include deer taken during the hunting season and the extended Community-Based Deer Management Permit program.

From 2003 through 2010, hunters averaged 86.0 deer/year (SE = 5.4) with no trend (Fig. 1). Deer–vehicle collisions decreased annually, but averaged 96.0/year (SE = 9.4). Sharpshooting harvests were fairly consistent after 2003 and averaged 154.0 deer/year (SE = 21.4). In 2011, sharpshooting did not occur because hunters said that they would increase effort in an attempt to reduce the herd. Two-hundred forty deer were reported removed, 171 via archery and 69 via DVC in 2011. In winter 2002, the aerial survey revealed that there were an estimated 16 deer/km^2, and the distance sampling estimate in 2011 was approximately 17 deer/km^2 (SE = 3.0).

Bernards Township

The deer population estimate at Bernards was about 34 deer/km^2 after 1 year of limited coordinated hunting in 2002. The removal of a reported 7,166 deer, including DVCs, reduced estimated density to about 18 deer/km^2 in 2011. Over the course of the program, annual DVCs were reduced by about 50%, from 275 in 2008 to 128 in 2010 (Fig. 2).

Upper Makefield Township

Initial (pre-2007) population estimates likely exceeded 35 deer/km^2. There were limited DVC data for Upper Makefield, but those available did show a decreasing trend with increasing number of deer removed (Table 2). Over the 3 seasons when hunting occurred (2007–2010), 1,414 deer were removed, including DVCs. Distance sampling efforts estimated a remaining deer density of about 18 deer/km^2 (SE = 5) after coordinated harvest efforts concluded in 2010.

Duke Farms

Initial (pre-2004) population estimates exceeded 80 deer/km^2 at Duke Farms. After removal of 866 deer by shotgun, archery, and limited sharpshooting (Fig. 3), the population estimate was about 12 deer/km^2 in 2011. After adding the number of deer harvested during staff-coordinated dispersal efforts back into the original forward-looking-infrared counts, the resulting estimated density without staff dispersal would have been about 18 deer/km^2.

Data Analyses

Deer densities for all study areas were significantly different over time; hunting reduced deer densities ($n = 15$, $F_{1,13} = 5.59$, $P = 0.034$, $y = -2.96x + 35.04$, $r^2 = 0.30$; Fig. 4). Additionally, from Year 0 to Year 3, there was a precipitous decline in deer densities at all sites ($n = 9$, $F_{1,7} = 8.84$, $P = 0.021$; Fig. 5). However, from Year 3 outward through Year 11, deer densities stabilized, and may have increased slightly ($n = 9$; $F_{1,7} = 1.27$, $P = 0.296$; Fig. 6).

DISCUSSION

Case Studies

Based on our data, traditional hunting in suburban settings was effective at reducing deer densities, but was unable to get densities below about 17 deer/km^2. This level was more than double the recommended densities of <8 deer/km^2 suggested for reductions of blacklegged ticks and associated incidents of Lyme disease (Rand et al. 2003, Stafford 2007) and maintenance of forest regeneration and biodiversity (Anderson 1984, Tilghmann 1989, deCalesta 1994, deCalesta and Stout 1997). Despite extended hunting seasons (up to 5 months), permitted use of bait, and no harvest limits, it appears that 17–18 deer/km^2 is within the range of diminishing returns for deer reduction in some suburban areas using traditional hunting. Once this density was achieved, there were fewer shot opportunities, deer likely became educated and retreated to non-hunted refugia (Williams et al. 2008), or hunters may have lost interest. This appeared to

Table 2. Upper Makefield Township, Pennsylvania, USA, harvests of white-tailed deer (*Odocoileus virginianus*) during archery and shotgun hunting seasons, sharpshooting, and deer–vehicle collision (DVCs) totals for 2006–2010.

Year	Archery	Shotgun	ND	Sharpshoot	DVCs
2006–2007	N/A	N/A	N/A	N/A	43
2007–2008	510	37	21	38	15
2008–2009	318	24	—	55	8
2009–2010	—	—	293	95	N/A

ND, not differentiated between archery and shotgun; N/A, not attempted.

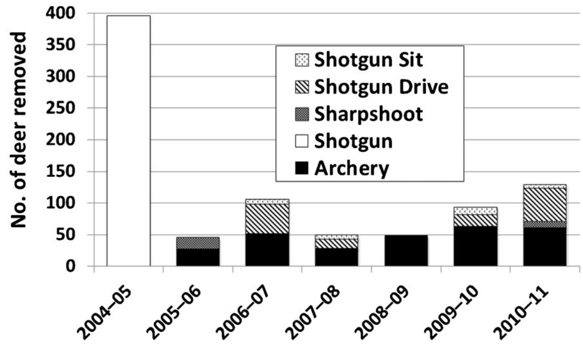

Figure 3. White-tailed deer (*Odocoileus virginianus*) harvest totals for coordinated removal efforts at Duke Farms, Hillsborough, New Jersey, USA, from 2004 to 2011.

occur around Year 3 of deer management efforts. After Year 3, hours/harvest increased to a point at which hunters maintained enough interest to keep the population stable, but further reduction was not achieved. This was likely the result of a majority of hunters dropping out of the program, while the more dedicated and efficient participants remained.

Historically, controlled hunting with firearms was effective at significantly reducing deer populations (Deblinger et al. 1995). Controlled hunting was highly effective and efficient at reducing deer populations on large open spaces in Massachusetts, USA (McDonald et al. 2007). This is likely the case for populations of white-tailed deer that are affected by severe winter weather, where deer managers at state wildlife agencies attempt to regulate deer abundance by carefully allotting permits for antlerless deer to hunters (Diefenbach and Shea 2011). In Connecticut, USA, local densities in a private community were reduced by 92% in 6 days using a shotgun–archery deer hunt, but that population initially consisted of <30 animals (Kilpatrick et al. 2002). Firearms-hunting was successful in reducing the deer herd at the George Reserve in Michigan, USA (McCullough 1984) and on a National Wildlife Refuge in Illinois, USA (Roseberry et al. 1969). Such controlled hunts can be successful with diligent oversight by managing agencies, near complete access by hunters, and primary use of firearms; conditions that rarely exist in most suburban environments.

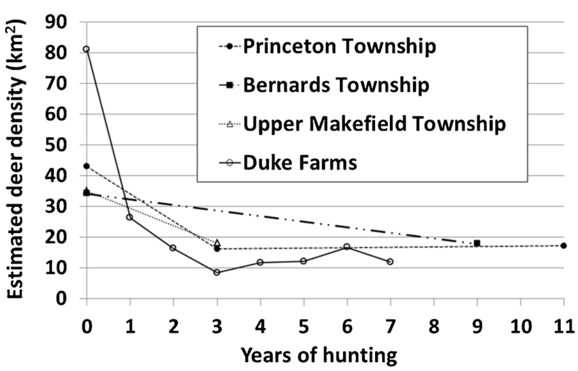

Figure 4. Scatter plot of white-tailed deer (*Odocoileus virginianus*) density and the number of years of hunting for Princeton Township, Bernards Township, and Duke Farms, New Jersey, USA; and Upper Makefield, Pennsylvania, USA. "Years of hunting" indicates duration of the program with year 0 representing the pre-hunt population estimate.

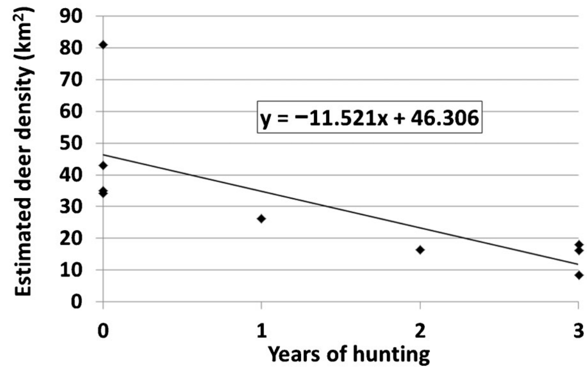

Figure 5. Scatter plot of pooled white-tailed deer (*Odocoileus virginianus*) density and the number of years of hunting for Princeton Township, Bernards Township, and Duke Farms, New Jersey, USA; and Upper Makefield, Pennsylvania, USA, from Year 0 to Year 3. "Years of hunting" indicates the duration of the program with year 0 representing the pre-hunt population estimate. Trend-line represents the least-squares estimate of linear relationship.

Recently, some managing agencies have witnessed the limitations in the ability of traditional hunting to significantly reduce deer densities. Agency sharpshooters in Wisconsin, USA, were 9–17 times more effective at removing deer infected with chronic wasting disease than were hunters, despite financial incentives for hunter-harvested deer that tested positive and a state-funded food pantry program for donating harvested deer that tested negative (Langenberg et al. 2009). Six years of extended hunting seasons (Sep–Mar) with no bag limits resulted in little cumulative change in deer density in chronic wasting disease–affected areas in Wisconsin (Samuel et al. 2009). Additionally, resistance by deer hunters themselves eroded this chronic wasting disease management strategy, and surveillance data suggested increased prevalence of chronic wasting disease during this time (Samuel et al. 2009).

Limitations in the Organized Use of Hunters

Homeowner communities and municipalities often use public health threats (e.g., DVCs and tick-associated diseases) to justify lethal deer-management programs to reduce over-

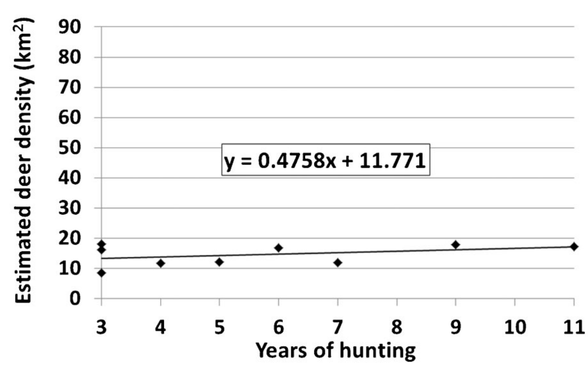

Figure 6. Scatter plot of pooled white-tailed deer (*Odocoileus virginianus*) density and the number of years of hunting for Princeton Township, Bernards Township, and Duke Farms, New Jersey, USA; and Upper Makefield, Pennsylvania, USA, from 3 to 11 "Years of hunting." Trend-line represents the least-squares estimate of linear relationship.

abundant deer populations (DeNicola et al. 2000, Stafford 2007, DeNicola and Williams 2008, Magnarelli et al. 2010). In such circumstances, hunting is the tool most often recommended by state wildlife agencies due largely to its minimal financial cost to stakeholders (Kilpatrick and LaBonte 2007, Anonymous 2008). However, we found that hunting in its present form is limited in its potential to reduce deer densities to levels desired by local communities (e.g., 10 deer/km^2 in the case of Bernards and Princeton) for the following reasons: 1) there were community members that would not allow hunting on their properties, resulting in only a portion of the local community accessible for hunting; 2) some hunters may desire greater densities for recreational interests and willing participation compared with objective levels set by community landowners (Anonymous 2010); 3) even with pre-hunt estimates of deer densities derived using sound methodology, landowners and hunters alike may not comprehend the number of deer that need to be harvested to achieve and sustain significant population reductions; and 4) hunters did not always take suitable precautions to prevent educating other deer to their presence, which is imperative for deer population-reduction efforts, particularly at high initial densities (Kilpatrick and Lima 1999, Williams et al. 2008).

The 3 suburban case studies (Bernards, Princeton, Upper Makefield) are good examples of concerted attempts to reduce deer densities. Though concerted, these efforts were limited in that 1) hunter density was only 1/1.2 km^2 in Bernards; 2) only 92 properties ($\approx$10%) of the 51.8-km^2 Upper Makefield were available to hunters; and 3) approximately 20% of Princeton was actively hunted. Though such hunter density might seem low for traditional hunting, it is appropriate when baiting to avoid effects of bait-site overlap (i.e., allowing deer access to multiple bait sites, thus reducing effectiveness of baiting). Unmanaged hunter activity occurred in all 3 locations, because there were no local restrictions on hunting. The scope of hunter access outside the structured programs was unknown.

Hunting was more successful in reducing densities at Duke Farms apparently because it was a smaller, non-residential area where hunters had full access, and refugia were actively eliminated by actions of non-hunting coordinators. Alternatively, when deer are hunted within only a portion of a residential community or municipality, there can be too many non-hunted refugia available, thus making reductions to objective levels, with traditional hunting only, difficult and unlikely. Even when hunters had complete access to the 800-ha Duke Farms and used intensive effort, deer retreated to neighboring suburbia, resulting in population reduction to about 12 deer/km^2.

An Enhanced Approach to Using Hunters to Manage Suburban Deer

We believe that regulated hunting, with some modifications, can be used to successfully further reduce deer densities. Often, a few skilled hunters with the interests of landowners in mind, can be more effective than many untrained hunters focused on recreation. Educating hunters regarding how to avoid negatively conditioning deer should increase harvest, but unconventional incentives may also need to be considered to retrain dedicated hunters. These incentives might include 1) making legal exceptions to typical hunting regulations to allow practices such as night-hunting from elevated positions using silent weapons and artificial illumination or light-gathering sights, 2) community assistance with carcass retrieval and delivery to the processor, 3) the community or landowner paying for carcass processing, or 4) partial reimbursement for hunter expenses (e.g., US$50/deer for fuel, hunting equipment, etc.).

One untraditional potential incentive, in modern North America at least, would be permitting the sale of deer killed beyond the needs of the hunters and other willing recipients. In the instance of overabundant deer, it might be necessary to provide this incentive to achieve densities in balance with the general public and natural ecosystems (VerCauteren et al. 2011). This goal-driven, carefully monitored harvest should bear little resemblance to the poorly regulated market-hunting of the late nineteenth century. Also, the traditional model of providing hunter education, which primarily focuses on safety, does not seem adequate to teach hunters how to more effectively harvest deer in overabundant suburban environments to meet density goals often set by local communities and landowners.

Many states have adopted harvest policies that are inconsistent; that is, they continue to acknowledge that urban and suburban deer populations are increasing, but nevertheless believe that their management efforts are working (Urbanek et al. 2011). Our experience is that suburban deer-management programs need to be administered and monitored rigorously, beyond simple harvest statistics, to determine whether goals are being met. We suggest that alternative, non-traditional methods, in addition to advanced hunter training, be considered if population densities $<$17 deer/km^2 within suburban settings are desired. Other tools, such as professional sharpshooting and reproductive control, may possibly have an additive or complimentary effect to hunter harvest through increased mortality and a reduction in recruitment.

MANAGEMENT IMPLICATIONS

Managing state agencies should play an active role in guiding members of the public and municipalities toward specific techniques, as described above, that will achieve deer density objectives rather than simply advocating for hunting in the name of deer management. State agencies should provide outreach information regarding what is required to manage hunters in a way that will result in meaningful population reductions. This effort could be facilitated by professional organizations, such as The Wildlife Society, by establishing an overabundant deer position statement, which would advise best management practices for state agencies and municipalities alike to achieve the difficult long-term goal of maintaining suburban deer densities at $<$10 deer/km^2. As management objectives for deer become more impact-oriented, state agencies will need greater resources to track public opinions about deer and their impacts on humans and to manage both public perception and long-term densities of deer. If suggested actions are heeded, we believe that hunters can help depress deer densities closer to community-desired densities, while also maintaining hunting as the preferred and primary deer-management technique. If hunters cannot, or will not, meet the density objectives of the general public, then hunting alone is not a solution to the management of overabundant deer. Ultimately, we suggest alternative methods for lethal removal of deer be considered to augment legal hunting programs where further reductions of deer are warranted.

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