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Achieving and maintaining sustainable white-tailed deer density with adaptive management

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Abstract: A leadership team developed an adaptive management program to reduce deer density and impact on a 29,642-ha forested demonstration area in northwest Pennsylvania incorporating goal setting, monitoring, and communicating with and motivating hunters. We linked reduction of deer density to environmentally sustainable levels with an appeal to the values of hunters (improving deer and habitat quality). The communication program educated and involved hunters as active participants in all phases of the management plan. We monitored deer density, deer impact, deer health, and hunter satisfaction to adjust numbers of permits for harvesting antlerless deer and to improve hunter access and use of all areas within the demonstration area. We reduced deer density and impacts to goal levels within 4 years and improved deer health. We maintained a base of satisfied hunters who continued to harvest enough deer to maintain goal levels of deer density and impact by the fifth year of the program, which continues to the present. Once we cut deer density in half with public hunting, maintaining deer density at the reduced (goal) rate was achieved with a relatively small pool of dedicated hunters who returned every year to harvest enough deer to offset recruitment.

Key words: adaptive management, *Odocoileus virginianus*, reducing population density, sustainable deer density, white-tailed deer

Literature on the negative impacts of overabundant white-tailed deer (*Odocoileus virginianus*) on forest ecosystems is extensive and comprehensive (DeGraaf et al. 1991, McShea et al. 1997, Rooney and Dress 1997, Horsley et al. 2003, Rooney and Waller 2003). In northwestern Pennsylvania, Tilghman (1989) reported that seedling regeneration required to reforest harvested areas would be adversely affected at deer densities above 7 deer/km^2. deCalesta (1994) noted that deer depressed songbird abundance and species richness when density was >5 deer/km^2, and deCalesta and Stout (1997) established that deer were in balance with local ecosystems when density in northeastern Pennsylvania was 4–6 deer/km^2.

After being nearly extirpated from northwestern Pennsylvania at the turn of the twentieth century, deer increased in abundance rapidly as restrictions on deer harvest reduced hunter harvest and amount of forage created by massive timber harvests opened up the understory (Figure 1). After Pennsylvania was clearcut statewide several times prior to the twentieth century, deer density skyrocketed until the late 1930s when a lack of deer forage, due in part to browsing by the overabundant deer herd, resulted in a large-scale deer die-off. Density plummeted to the levels identified with successful forest regeneration, healthy bird populations, and habitat improvements. The second-growth forest resulting from clearcutting during the 1880s to 1900s was harvested again in the 1940s to 1980s, producing increased amounts of forage followed by an increase in deer density, again fostered in part by restrictions on antlerless deer hunting. A second series of severe winters in the late 1970s, coinciding with another sustained increase in deer density, was followed by a second deer die-off associated with a leveling off of timber harvest and resulting reduced deer forage production. Deer density again declined in the 1990s following restrictions in timber harvest, restrictions in forage creation, and liberalized hunting seasons for antlerless deer. Timber harvest stabilized from 2000 to 2012 coinciding with stabilization of deer density that resulted from liberalizing deer harvest (concurrent buck-doe seasons, greater availability of antlerless permits, and a 3-point antler restriction) that reduced the number of deer available for harvest and likely resulted in more hunters harvesting antlerless deer.

The most widely used approach for managing white-tailed deer density and damage to forest resources is population control using public hunting to reduce deer density to target levels (Matschke et al. 1984, Rooney 2010, Kammin 2016). An ideal solution would be for natural resource agencies to issue enough permits for harvesting additional (antlerless) deer and to extend or make open-ended deer hunting season lengths to achieve desired harvest of deer.

Unfortunately, reality trumps the ideal in white-tailed management. Hunters, biologists, and natural resource agencies usually cannot agree on what constitutes desirable deer density. Many hunters want deer density associated with maximum sustained yield (MSY; deCalesta and Stout 1997, Frye 2006). Conversely, deer biologists and foresters want deer density associated with successful regeneration of understory vegetation and diverse plant and animal communities, which requires deer density far lower than that at MSY (deCalesta and Stout 1997). Natural resource administrators responsible for setting season and bag limits for managing deer density are caught between these 2 poles. Unfortunately, if hunting regulations result in lowered deer density, many hunters will stop hunting in such areas, resulting in reduced deer harvest and a return to higher deer densities. In the event that hunting regulations and subsequent deer harvest result in the deer density desired by biologists to sustain ecosystems and herd health, maintaining hunting pressure required to keep deer density at desired levels is difficult.

In 2000, a team of forest landowners, hunters, wildlife and forestry scientists and managers, ecologists, local entrepreneurs, and natural resource agency personnel in northwest Pennsylvania formed the Kinzua Quality Deer Cooperative (KQDC) to determine whether public hunting could be managed to reduce and maintain deer density at levels compatible with sustainable forest communities (deCalesta 2012, Stout et al. 2013). This paper describes the adaptive management approach developed by the cooperative for achieving and maintaining an ecologically sound deer density.

KQDC demonstration area

The 29,642-ha demonstration area (DA) was located within the northern portion of the Allegheny National Forest in northwestern Pennsylvania (Figure 2). The heavily forested landscape was managed by 2 public organizations comprising 82% of the DA (Allegheny National Forest and Bradford Water Authority) and 2 private landowners comprising 18% of the DA (Collins Pine and Forest Investment Associates). The DA was representative of forested areas with high deer density and impact on commercially valuable tree species such as black cherry (*Prunus serotina*), red and sugar maples (*Acer rubrum* and *A. saccharum*), and northern red oak (*Quercus rubra*). The DA was comprised of a mix of age classes of northern hardwood forest managed with even- and uneven-aged silviculture for sustainable production of timber and other forest resources.

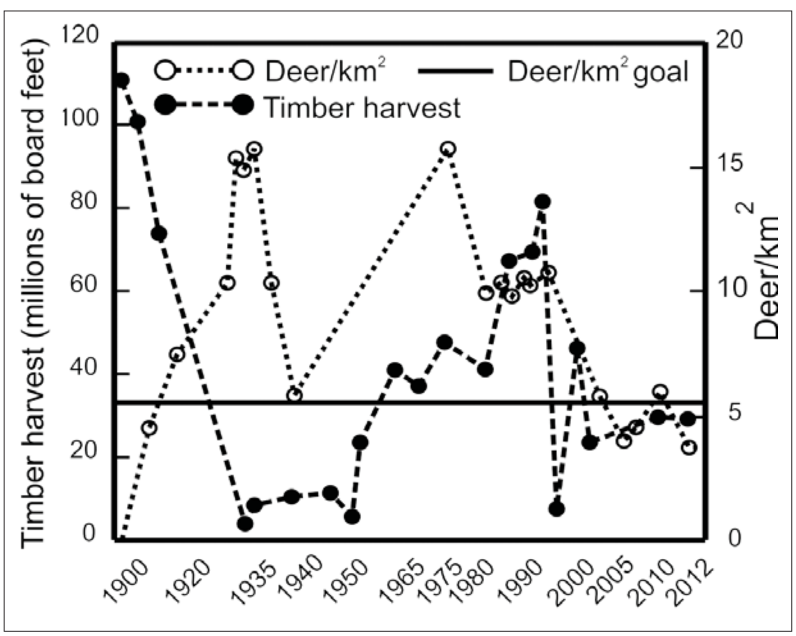

Figure 1. Trends in deer density and timber harvest on the Allegheny National Forest 1900–2012 (after Redding 1995 and Stout et al. 2013). Solid horizontal line represents desired deer density for species richness and abundance of all forest resources.

Prior to implementation of the adaptive management program, deer density was 11 deer/km² and impact on forest regeneration was rated as heavy to severe with few regenerating tree seedlings of any species present. The

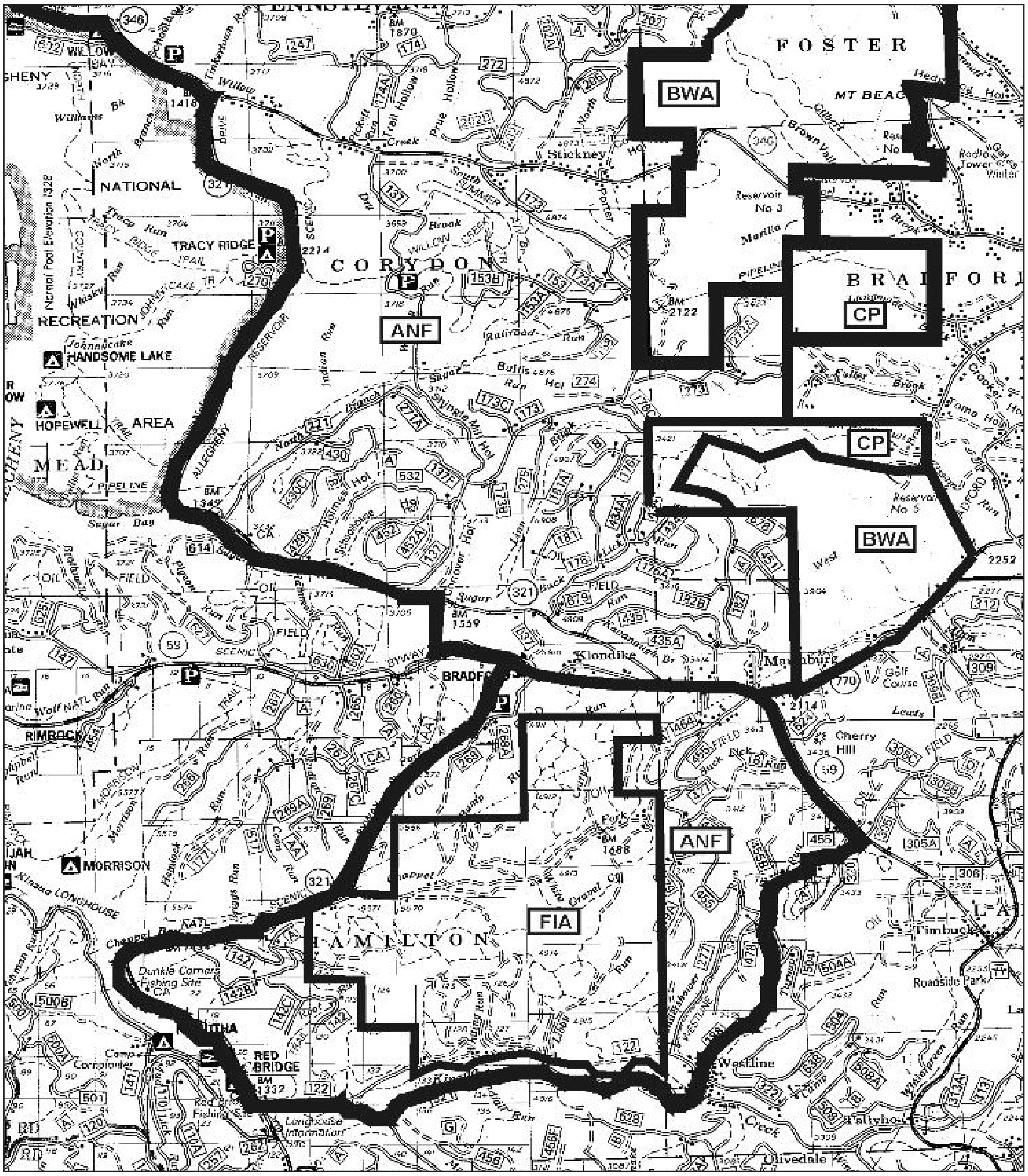

Figure 2. Ownership patterns on KQDC demonstration area: ANF = Allegheny National Forest; BWA = Bradford Watershed Authority; CP = Collins Pine; and FIA = Forest Investment Associates.

Pennsylvania Game Commission (PGC), recognizing that deer density was too high in the management unit (2F) encompassing the DA, annually made permits available for harvesting antlerless deer in unit 2F in an attempt to lower deer density and impact.

Management strategy

The KQDC leadership team used established literature on the relationship between deer and forest resources as the basis for development and implementation of the management plan, with the goal of reducing deer density to ecologically sustainable levels (4–6 deer/km^2) by public deer hunting. However, years of fruitless testimony by leadership team members on the science-based need for reduction of deer density at annual season and bag limit hearings by the PGC brought home this reality: values and culture of deer hunters have greater influence than scientific information over commissioners tasked with setting deer season and bag limits. The commissioners declined to offer sufficient numbers of permits to reduce deer density to ecologically sustainable levels, although aware of the need to reduce deer density as recommended by deer biologists within the PGC. However, they did authorize issuance of permits for harvesting antlerless deer.

Integration of science and values

In 2000, the PGC revamped its deer management program under the leadership of Gary Alt to bring deer density and impact under control. Alt's experience with bear hunters provided him with the key insight into management of game animals: that culture and values of hunters must be acknowledged, respected, and integrated with science to produce a viable management program. He developed and delivered an educational program for deer hunters (and other stakeholders) across Pennsylvania that emphasized reduction of deer densities to levels compatible with producing quality deer habitat (primarily forage) and quality deer, 2 values important to deer hunters. The educational program was accepted and endorsed by deer hunters, and paved the way for the PGC to enact additional hunting regulations designed to reduce deer density and improve deer and habitat quality.

Alt parlayed his acceptance by hunters into approval by the PGC for 3 regulations designed to reduce deer density and improve deer quality statewide. A concurrent antlered-antlerless deer season was approved during 2001, which allowed hunters to harvest antlerless deer during the season for antlered deer when most hunters are afield. A 3-point antler restriction was adopted in 2002, which limited harvest of antlered deer to those with at least 3 antler points on a side, thereby nearly eliminating the harvest of yearling bucks and allowing them to survive to grow larger and more impressive antlers. A Deer Management Assistance Program (DMAP) was instituted in 2003, which allowed landowners with excessive deer damage to obtain additional permits for harvest of antlerless deer and distribute them to hunters for hunting specifically on their lands. Finally, the PGC increased numbers of antlerless permits allocated to many management units, including the one encompassing the DA.

The KQDC leadership team observed the success of the approach taken by Alt and patterned its approach similarly. A well-advertised town hall meeting was conducted in 2001 with local deer hunters, Alt presented his program as lead speaker, and KQDC spokespersons outlined a program integrating science and hunter values, concluding the meeting with an exhibit of trophy antlers harvested in years past from the DA.

The KQDC leadership team embraced the 3 deer hunting regulations promulgated by Alt. It developed an aggressive DMAP program to effect the desired reduction in deer density and impact that included splitting the DA into 2 (northern and southern) DMAP units. Additionally, the KQDC leadership team responded to 3 requests hunters commonly made of the PGC: provide estimates of local deer density; conduct check stations during deer hunting season to characterize deer health; and reduce management units from current size of large, heterogeneous areas (many thousands of ha) to smaller, more homogeneous units of a size reflective of local deer habitats and easier to administer and adopt hunting regulations tied to smaller locales. These requests were accommodated on the DA by development of a monitoring program that included annual estimates of deer density and check stations for harvested deer and designation of DMAP units producing de facto management areas of a size compatible with hunter requests.

Monitoring

The KQDC leadership team developed a monitoring program to address hunter requests for information and to provide data for scientific management of the deer herd. All data were collected annually (2002–2012) for estimating deer density and deer impact, sex and age ratios, and recruitment for the pre-hunt herd, deer herd health (from harvest data), and hunter satisfaction. Because there were no proven-effective protocols or methods for estimating deer density and impact, I developed and utilized methodologies and analyses for such and published them to establish credibility (deCalesta 2013, Pierson and deCalesta 2015). These are discussed next:

Deer density. I laid a grid of 105 numbered points 1,610 m apart in north-south and east-west orientation over the DA and randomly selected 26 points as sites for collecting deer density data. At each of the selected points, I placed a grid of 5 transects 1,610 m long and spaced 300 m apart such that the selected point formed the mid-point of the middle transect. I laid out all transects on a compass bearing of 0° (true north, corrected for declination of 12° NW). Technicians counted deer pellet groups within 52 circular plots (1.2-m radius) 30.5 m apart along each transect. I constructed 5 replicate samples by assigning each transect within each of the 26 grids of 5 transects a number of 1–5 randomly. Replicate 1 was comprised of all transects assigned the number 1 from the 26 grids, replicate 2 was comprised of all transects assigned the number 2 from the 26 grids, and so on for 5 replicates of 26 transects. I estimated deer density per transect line and derived 5 replicate estimates of deer density using the analysis developed by deCalesta (2013). Pellet counts were conducted after snow melt (normally after mid-March) and before green-up of ground vegetation (normally after mid-May).

I used a 2-sample τ-test (SYSTAT 2013) between deer density for 2002 and 2005 to determine whether our adaptive management steps resulted in reduction of deer density. To determine whether we were able to maintain deer density at goal, I used regression analysis (SYSTAT 2013) to determine whether deer density remained stable from 2005 to 2012.

I compared deer density in spring with number of management unit and DMAP permits issued for the previous fall hunting season to determine whether changes in numbers of MU antlerless permits and DMAP antlerless permits were associated with changes in deer density. If the numbers of permits affected deer density, I expected that increased numbers of permits would be associated with reduced deer density the following spring and vice versa.

Deer impact. I estimated deer impact on woody species at the same time and from the same plots as for deer density (excepting that impact data were collected from every other deer density plot). Rather than record impact on all woody species, I selected 6 species representative of a wide range of deer impact based on locally observed deer preferences and resistance to browsing. Preferred indicator species were red maple and eastern hemlock (*Tsuga canadensis*); moderately preferred indicator species were black and yellow birches (*Betula* spp.) as a single indicator species and black cherry: browse-resistant indicator species were American beech (*Fagus grandifolia*) and striped maple (*Acer pensylvanicum*).

I recorded levels of impact on plants >15 cm tall and <2 m tall. Because seedlings <15 cm tall reflect current germinates that may not survive due to multiple factors (drought, disease, heat, insect defoliation), seedlings <15 cm tall were not assessed for impact except in the case where the seedling had been severely browsed for years, which prevented it from growing >15 cm tall. Impact on seedlings >2 m tall was not recorded, as these seedlings were considered to have grown out of the reach of deer.

I calculated impact at 2 levels: zero to moderate (<50% of stems browsed and seedlings not hedged), representing impact that would not prevent seedlings from becoming established and growing out of browsing reach of deer; and heavy to severe (>50% of stems browsed and seedlings hedged), representing level of deer browsing that would result in failure of seedlings to grow out of reach of deer. Hedging refers to suppression of seedling growth related to repeated deer browsing: hedged plants are stunted in height and stems are browsed back to short, thick stubs.

As with deer density data, I estimated deer impact per indicator species per transect line and derived 5 replicate estimates of deer impact. I used methodology developed by Pierson and deCalesta (2015) to estimate deer impact on indicator species. I determined whether deer density affected impact levels by regressing impact level for the 6 indicator species at zero to moderate and heavy to severe levels on deer density.

Each year, the same experienced foresters collected deer density and impact data during March to May when there was no snow cover or fern growth to obscure pellet groups or seedlings. I recorded density and impact data within unfenced forest stands. Density and impact data were not collected from plots that fell within harvested sites, which were fenced to keep out deer.

Deer harvest. I collected data on deer health (sex, age, weight, and antler characteristics), location of harvest, day of harvest, and location within DA of harvested deer during hunting season at 2–3 check stations located on major access roads. Check stations were run on days when most deer are harvested (first 2 days of deer season and the following Saturday).

Sex, age ratios, and recruitment. Recruited hunters collected sex and age data from 6 roadside routes distributed representatively across the DA during late summer to early fall. Individual routes were run >6 times each fall; total length of all routes was 85 km. Recruitment rate was estimated by dividing number of fawns by sum of adult buck and doe deer.

Hunter satisfaction. Prior to 2008, I recorded informal feedback from hunters during check station operations, conduct of roadside counts, and during workshops. Beginning in 2008, I assessed hunter satisfaction from hunter responses to a questionnaire given to hunters bringing harvested deer to check stations.

Adaptive management

Adaptive management is a structured method for learning by doing that includes goals, use of practices to achieve the goals, implementing and monitoring the practices, assessing how the practices succeed in achieving the goals, and adjusting management in response to the assessments (Lee 1993, Lancia et al. 1996). The leadership team adopted this strategy for achieving goals for deer density (4–6 deer/km^2) and impact levels (zero to moderate) on the DA by a number of adaptive practices.

Solicitation/involvement of alpha and beta hunters. Alt (2006) identified 3 groups of hunters: alpha, beta, and omega. Alpha hunters are capable of consistently harvesting deer every year. They are well-informed on the science of deer biology and management, deer hunting strategies and techniques, and understand that for habitat to produce healthy and trophy animals, deer must be in balance with their habitat. Because alpha hunters harvest the majority of deer, the leadership team decided to cultivate, maintain, and recruit these hunters with the message that deer density must be managed at the level that produces habitat supporting trophy deer and deer of high food value. Beta hunters are alpha hunters in the making: open to scientific evidence regarding the bases for managing deer, developing hunting skills, and aware of the relationship between deer density and deer and habitat health. We utilized the same message for beta hunters as for alpha hunters, but realized that beta hunters needed more cultivation, maintenance, and recruitment than alpha hunters.

Omega hunters depend on culture and hunting lore for their understanding of deer management and desirable deer density and are less successful than alpha and beta hunters in harvesting deer (Alt 2006). Omega hunters want deer density at MSY or higher and will not accept information indicating that this density is neither sustainable nor results in optimal deer and habitat health.

For alpha and beta hunters, the message that resonated was that deer health/trophy status and habitat health (for deer and other game species such as grouse and turkey) are optimal when deer density is at or below seedling regeneration carrying capacity. However, there is no message that will appeal to omega hunters that also promotes sustainable deer density. We sympathized with omega hunters and accepted their values and culture, but directed management efforts on the DA, including education and communication, to meeting the needs of alpha and beta hunters and on resources affected by deer density and impact.

We developed activities designed to educate and involve alpha and beta hunters to achieve their buy-in and participation in deer harvest. We conducted 1-day deer density and impact workshops during the spring from 2001–2008 wherein the science of deer management was detailed, including methods for collecting, analyzing, and incorporating monitoring information into deer management. Hunters and other stakeholders collected deer density and impact data, which were used in the workshop to estimate deer density and impact and formed the basis for making management recommendations including reduction in deer density through hunting harvest. Hunters collected roadside deer data, were invited to participate in annual deer density and impact data collection (in addition to the workshops), were active members on the KQDC leadership team, and contributed to deer health data by bringing deer they harvested to check stations. After 2008, numbers of hunters and other stakeholders signing up for the spring density and impact were too low to justify conducting the workshops: possibly we had exhausted the available pool of stakeholders and all interested persons had attended one or more of the workshops.

Incentives for harvesting deer. Hunters bringing harvested deer to check stations received a lottery ticket (and invitation to an annual hunter appreciation banquet) for harvesting an antlered deer and 2 tickets for harvesting an antlerless deer. Ticket holders received a discount (half-price) for the banquet, were entertained by informative talks by prominent deer writers, and were entered into a raffle for hunting items (black powder rifles, knives, hunting hats, and other hunting paraphernalia).

Improving hunting access. Research conducted in Pennsylvania by Keenan (2010) indicated that hunters rarely travel >600 m from access roads while hunting deer. Most of the area within the Allegheny National Forest component of the DA was within 600 m of graveled, maintained U.S. Forest Service roads and was likely to be used for hunting. Large swaths of lands within the Bradford Water Authority and Collins Pine ownerships were >600 m from roads; the roads were not well marked and not as well maintained as on the National Forest. Roads built for oil and gas exploration and extraction on Forest Investment Associates lands provided a network of roads, such that no places in the properties were >600 m from a road. However, these roads presented a confusing network of often-changing and temporary access roads and were not well maintained. I attempted to improve hunter access to the Bradford Water Authority, Collins Pine, and Forest Investment Associates lands by providing maps of the areas, and on Forest Investment Associates lands, we color-coded roads on maps and on site (colored flagging on wooden laths) to help hunters identify access roads. Where possible, forest roads within the DA and especially in the Allegheny National Forest were plowed after snows to keep them open for hunting.

Communicating with hunters. Descriptions of the KQDC deer management program were published in local news outlets and outdoor writers were provided copy for informing hunters of the program. A database of hunter contact information (mailing addresses, email addresses) was assembled from data collected from hunters bringing harvested deer to check stations, and these hunters were apprised of management activities on the DA as well as invited to annual hunter appreciation banquets. A website (<<http://www.kqdc.com>>) was developed that provided hunters with background information on the KQDC program, downloadable maps of the DA including locations of access roads and check stations, lodging and restaurant information, and instructions on how to obtain antlerless permits, including DMAP permits. Hunters were encouraged to hunt within areas of high deer density on the DA, which were identified on maps made available on the website, through news releases, and at check stations. Annual progress reports were provided to hunters attending the hunter recognition banquet and were posted on the KQDC website. The leadership team developed a blog, and Facebook and Twitter identities for hunters to obtain additional information and to interact with the leadership team and other hunters.

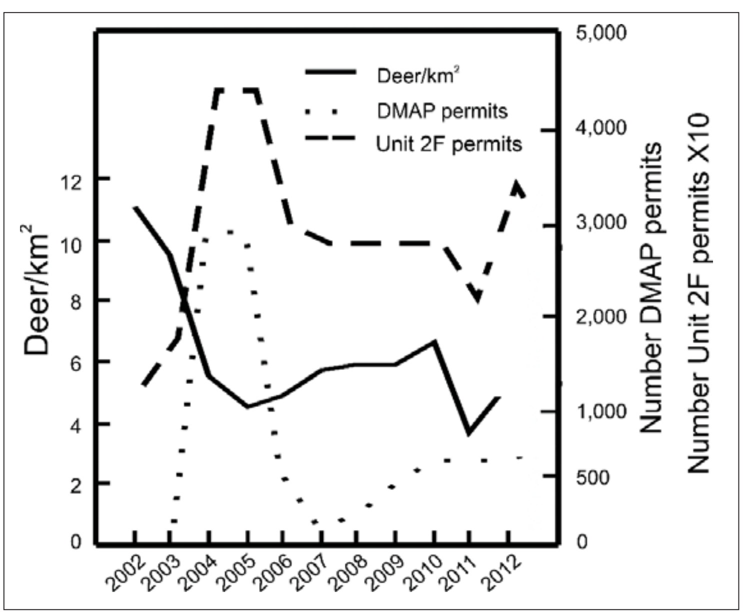

Figure 3. Spring deer density (year X) compared with numbers of MU2F and DMAP antlerless permits issued the previous fall (year X - 1).

Adjusting number of antlerless permits. Numbers of DMAP permits were adjusted annually as deer density increased/declined on DMAP units. Because numbers of deer harvested on the Bradford Water Authority and Collins Pine properties in the northern DMAP unit were much lower than on the Allegheny National Forest portion (and deer density was higher), this DMAP unit was divided into 2 units (Allegheny National Forest portion as one and Bradford Water Authority and Collins Pine portions combined into the other) based on similarity of road access, deer density, deer impact, and magnitude of deer harvest. Hunters were directed into areas with high deer density with maps identifying areas of high deer density and road access.

Results and discussion

Deer density and antlerless permits

Prior to availability of DMAP permits in 2003, deer density was high and numbers of unit 2F permits were relatively low (Figure 3). As numbers of unit 2F permits climbed and DMAP permits became available in 2003, there was an immediate and large drop in deer density the following spring. As deer density continued to decline, numbers of DMAP antlerless permits were reduced until deer density reached the target level in 2007. Deer density in the ensuing years fluctuated and was echoed by changes in number of DMAP permits: when deer density declined, numbers of permits made available the following fall were reduced, and when deer density increased, numbers of permits available the following fall increased. Initial reduction in deer density from 2002 (10.5 deer/km^2) to 2006 (4.5 deer/km^2) was significant (t = 11.9, N = 5, P < 0.001). Despite fluctuations in deer density 2006-2015, average deer density for the period (mean = 5.4 + 0.6 deer/km^2) did not vary (r^2 = 0.02, β = -0.04, P = 0.68) and remained at goal.

Vastly more antlerless permits were available each year for unit 2F than for DMAP (Figure 3) as the DA comprised only a small portion (~5%) of unit 2F. The KQDC leadership team was able to manipulate annual numbers of DMAP permits but had no influence over the number of unit 2F permits available. Regardless,

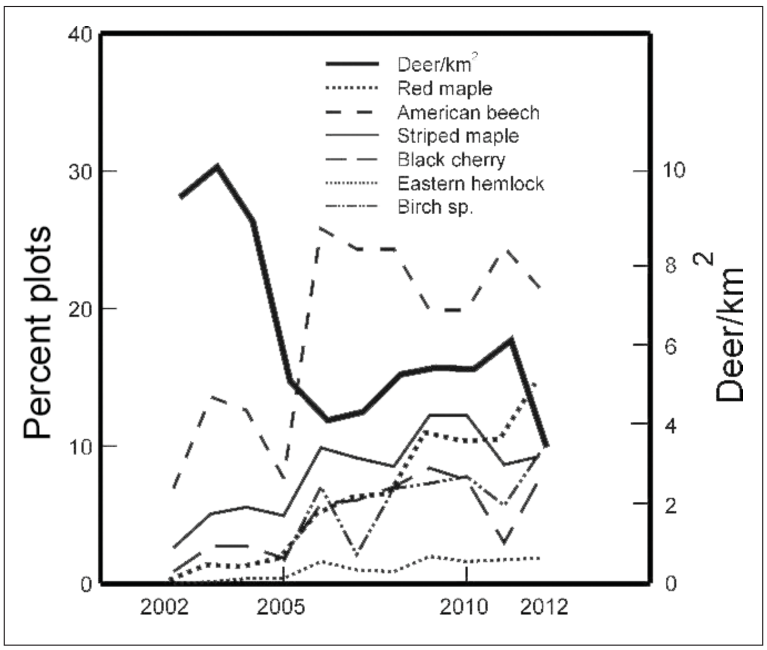

Figure 4. Percent plots zero to moderate impact on indicator species and deer density.

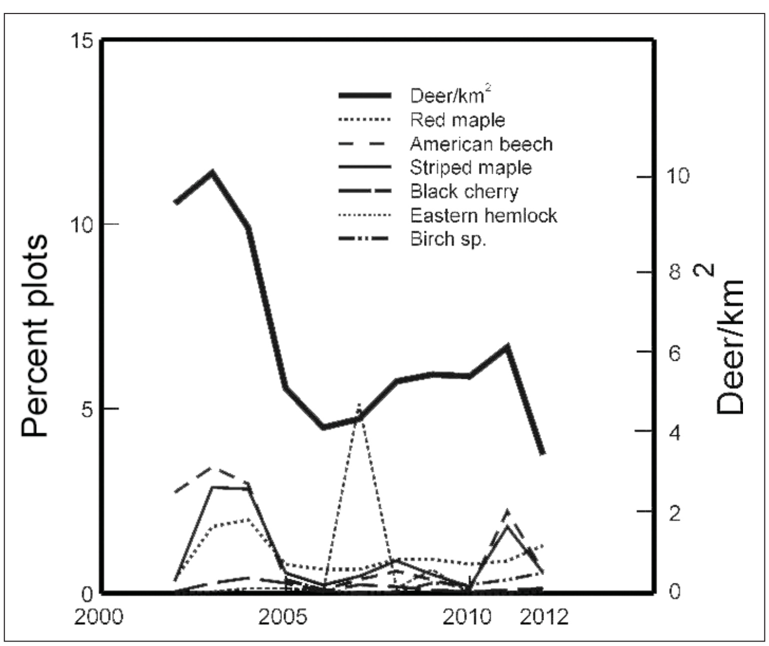

Figure 5. Percent plots heavy to severe impact on indicator species and deer density.

the overall pattern was clear: as DMAP permit numbers increased, deer density the following spring decreased and vice versa. As numbers of unit 2F and DMAP permits more or less stabilized after 2007, so did deer density at target density.

Deer impact

Percent plots with regeneration exhibiting zero to moderate and heavy to severe levels of impact initially were low (Figures 4 and 5), indicating high deer impact prior to implementation of the DMAP program. There was virtually no tree seedling regeneration present.

As deer density decreased on the DA, percent plots with indicator species at impact levels reflective of successful regeneration potential (zero to moderate impact) increased (slopes of lines regressing percent plots with deer density were inversely related to density [$P < 0.001$] for all indicator species; Figure 4).

Conversely, slopes of lines regressing percent plots heavy to severe impact with deer density were positive for all indicator species and significant ($P < 0.05$) for 3 species (red maple, American beech, and birches), indicating that the relationship between deer density and heavy to severe impact was positive. As deer density decreased, percent plots with heavy to severe impact decreased and vice versa (Figure 5). The apparent spike in impact on eastern hemlock in 2007 is attributed to a spike in germination of deer-preferred hemlock seedlings in 2006, followed by a spike in hemlock germinants that grew into the height interval (>0.5 m) in 2007 when impact would have been documented.

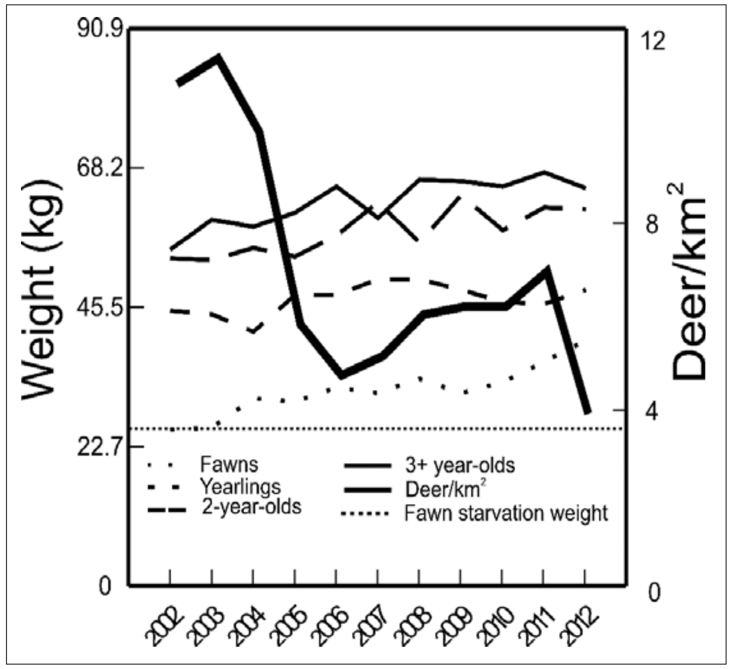

Figure 6. Increase in buck body weight as deer density declined.

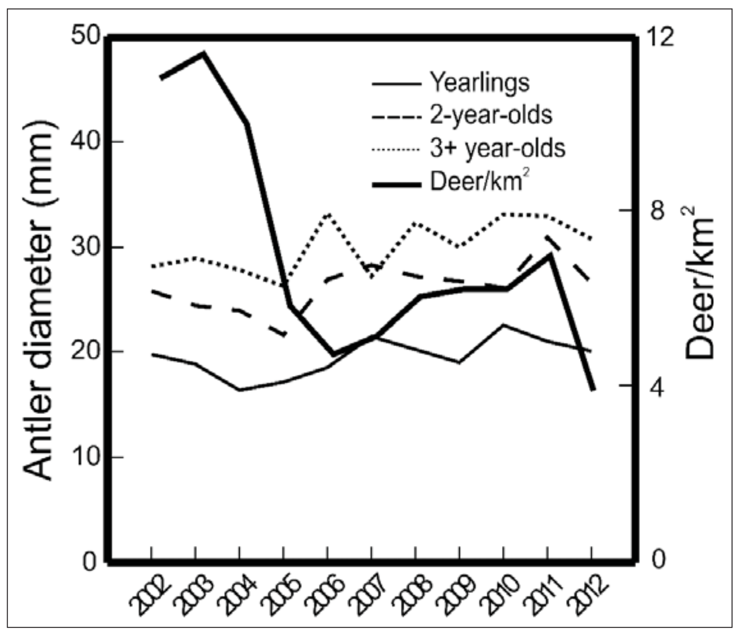

Figure 7. Increase in antler beam by age class with decrease in deer.

Deer harvest

Indices of herd health (body weight and antler characteristics; Figures 6 and 7) improved significantly as deer density was reduced (deCalesta 2012, Stout et al. 2013).

Locations of deer harvested and brought to check stations represented a dichotomy of harvest (Figure 8). Most deer were harvested from the Allegheny National Forest portions of the DA wherein roads were well signed and well maintained. On Forest Investment Associates, Bradford Water Authority, and Collins Pine portions of the DA, roads were not well marked or as well maintained and formed a confusing

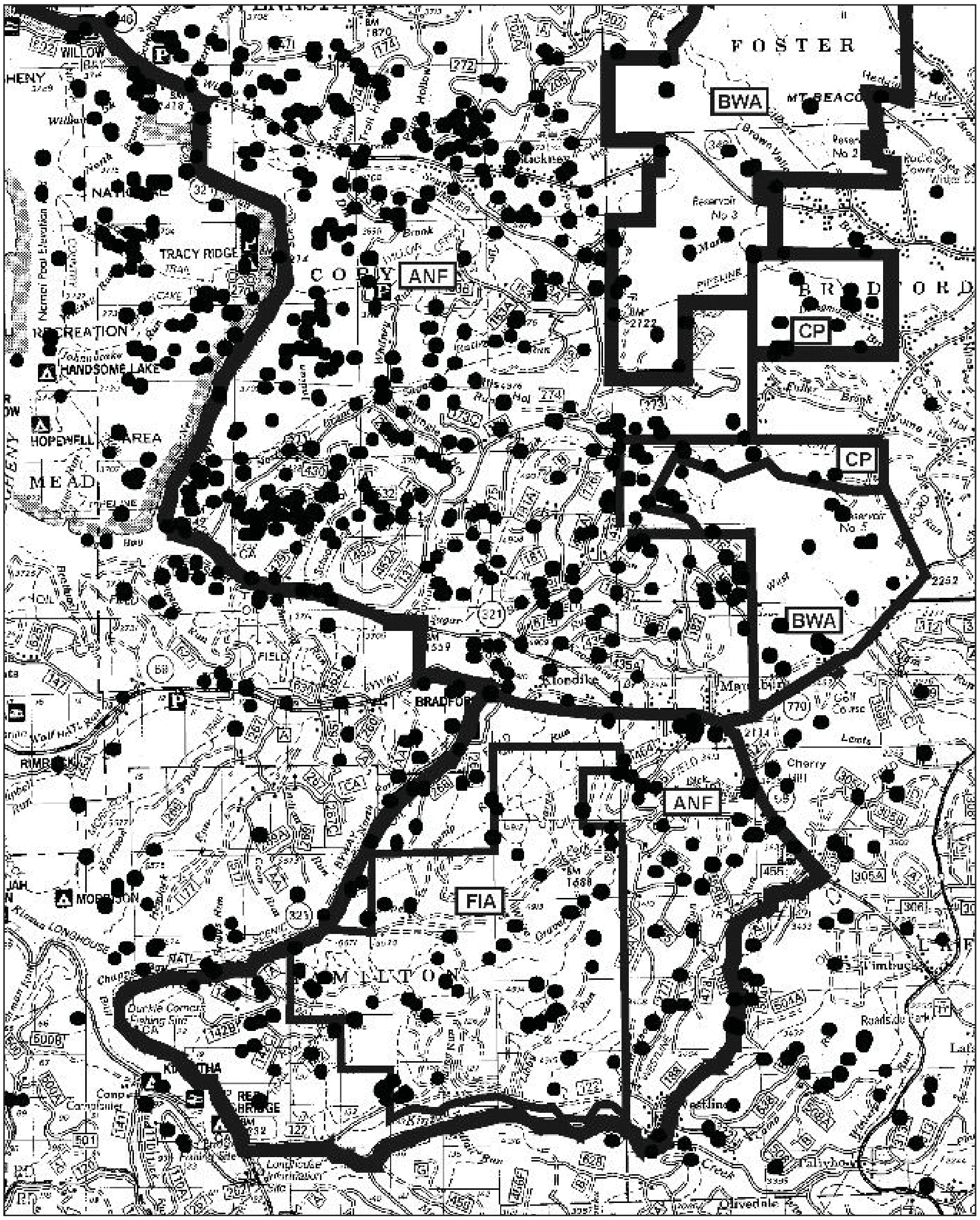

Figure 8. Locations of deer harvested on the KQDC demonstration area and brought to check stations, 2002–2010.

network of intertwining roads on the Forest Investment Associates portion. These differences in harvest locations and intensity led to the above-mentioned creation of 2 DMAP units from the single unit initially established for the northern half of the DA. The intent was to direct hunting effort to the Bradford Water Authority and Collins Pine portions of the DA to increase harvest and reduce deer density and impact.

Sex/age characteristics and size of harvest

As deer density declined on the DA, the number of deer harvested and brought to check stations declined similarly (Figure 9). Reduction in harvest is, in part, related to reduction of hunting pressure: an annual count of hunter vehicles on a 20-mile stretch of access road the first day of the rifle season was initially in the neighborhood of 200 vehicles but then declined to <100 during 2006–2012. Deer harvest the first year of DMAP availability (2003) was predominantly antlerless deer. As deer density and harvest declined sharply (2003–2006), hunters brought roughly equal numbers of antlered and antlerless deer to check stations,

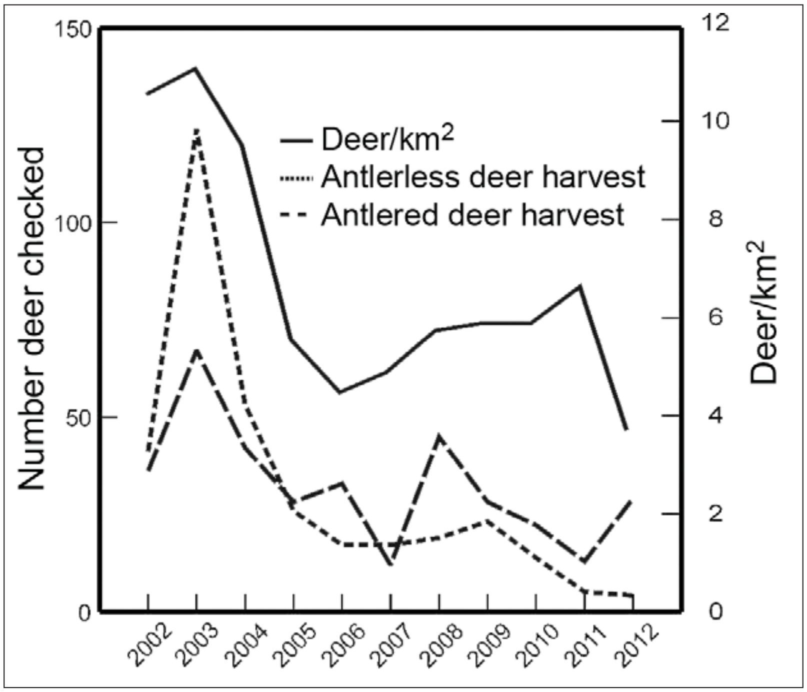

Figure 9. Composition of deer brought to check stations by antler classification.

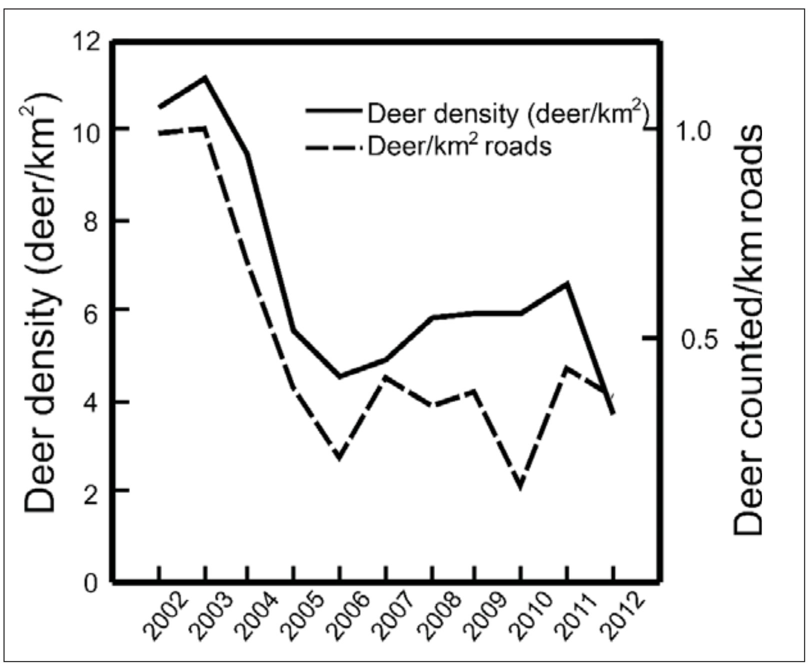

Figure 10. Comparison of roadside deer counts with spring deer density.

signaling a shift in hunting effort from primarily antlerless deer to an increasing trend of more antlered than antlerless deer.

I estimated that hunters brought about 10% of harvested deer to check stations by comparing numbers of deer harvested with DMAP permits and reporting them to the PGC (mandatory) with numbers of deer harvested with DMAP permits and brought to check stations. I assumed that the ratio of antlerless:antlered deer brought to check stations mirrored the ratio in total harvest on the DA and reflected a change in hunter harvest of antlered vs. antlerless deer as density declined; hunters were preferring to harvest antlered deer.

Roadside counts (deer counted per km of forest roads) declined over time concurrent with falling spring deer density and stabilized after 2006 when deer density also stabilized (Figure 10).

Hunter satisfaction

Beginning in 2008, hunters bringing harvested deer to check stations filled out a survey to assess opinions of successful hunters. By 2008 the deer herd had been reduced from starting density in 2002 by approximately 50% for several years, so it is fair to assume that by then most or all omega hunters had quit hunting the KQDC. On a scale of 1 to 10 with 10 representing complete satisfaction with deer management and 1 representing complete dissatisfaction, the average satisfaction score hovered between 6 and 7. Over 90% of hunters indicated they would hunt the KQDC over the next 5 years, and when asked what would make them stop hunting, the most frequent answer was "too old, no longer able to hunt."

Because I did not isolate and separately analyze factors likely contributing to getting the herd to goal density and keeping it there, I am unable to determine whether any one or several adaptive management factors had more or less impact on achieving the goals of reducing deer density and impact. I do know that in concert, adaptive management activities were associated with reducing deer density to goal and maintaining it there, that deer health improved, that deer impact was significantly reduced, and that hunters were sufficiently satisfied with deer management that they returned annually to harvest enough deer to stabilize density at goal. I recommend that forest land managers desiring to manage deer density and impact incorporate as many of the adaptive management steps we employed as possible, using monitoring to make changes in activities as indicated.

Once density of a managed white-tailed deer herd stabilizes at target level, harvest of enough deer to offset recruitment of fawns will ensure maintenance of that density. The relatively low pre-hunt fawn:doe ratio, which averaged 42:100, was probably less related to predation and more related to the average antlered buck:doe ratio of 1:5. With so few adult bucks per doe, it is likely some does were not bred on the KQDC every year. Roadside counts indicated that numbers of black bears (*Ursus americanus*), coyotes (*Canis latrans*), and bobcats (*Lynx rufus*) remained fairly constant and thus would have had a much lower impact when herd density was higher (2002–2004). Apparently, once deer density reached goal, hunter harvest, with a likely assist from predation, removed enough deer annually to offset recruitment and stabilize density.

None of the adaptive management activities, including monitoring which was performed by employees of the cooperating landowners and by hunters, required investment in costly equipment or labor. But such activities, especially those concerning deer density and impact, need not be restricted to those utilized on the DA. Rather, I recommend that individual landowners utilize monitoring techniques based on science that are also affordable so they can conduct them on a regular basis.

I was able to subdivide the DA into smaller, more internally consistent units, which allowed me to better direct hunting effort and tailor steps designed to improve hunter access.

Although I have no evidence, I surmise that the omega hunters chose to hunt elsewhere; as deer density declined to goal, I received fewer complaints at annual check stations about how "there weren't any deer on the KQDC." I believe that the remaining alpha and beta hunters found sufficient rewards in quality of deer harvested and hunting conditions within the DA that they continued to hunt the DA and harvested enough deer every year to maintain deer density at goal.

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Literature cited

Alt, G. 2006. Forward. Pages ix–xiii *in* Frye, B. Deer wars: science, tradition, and the battle over managing whitetails in Pennsylvania. Penn State Press, State College, Pennsylvania, USA.

deCalesta, D. S. 1994. Impact of white-tailed deer on songbirds within managed forests in Pennsylvania. Journal of Wildlife Management 58:711–718.

deCalesta, D. S. 2012. Collaboration among scientists, managers, landowners, and hunters: the Kinzua Quality Deer Cooperative. Pages 191–2009 *in* J. P. Sands, S. J. DeMaso, M. J. Schnupp, and L. A. Brennan, editors. Wildlife Science: connecting research with management. CRC Press, Boca Raton, Florida, USA.

deCalesta, D. S. 2013. Reliability and precision of pellet-group counts for estimating landscape level deer density. Human–Wildlife Interactions 7:60–68.

deCalesta, D. S., and S. L. Stout. 1997. Relative deer density and sustainability: a conceptual framework for integrating deer management with ecosystem management. Wildlife Society Bulletin 25:252–258.

DeGraaf, R. M., W. H. Healy, and R. T. Brooks. 1991. Effects of thinning and deer browsing on breeding birds in New England oak woodlands. Forest Ecology and Management 41:179–191.

Frye, B. 2006. Deer wars: science, tradition, and the battle over managing whitetails in Pennsylvania. Penn State Press, State College, Pennsylvania, USA.

Horsley, S. B., S. L. Stout, and D. S. deCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. Ecological Applications 13:98–118.

Kammin, L. 2016. Living with white-tailed deer in Illinois. Office of Sustainability, University of Illinois, Urbana, Illinois, USA.

Keenan, M. T. 2010. Hunter distribution and harvest of female white-tailed deer in Pennsylvania. Thesis, Pennsylvania State University, State College, Pennsylvania, USA.

Lancia, R. A., C. E. Braun, M. W. Collopy, R. D. Dueser, C. J. Martinka, J. D. Nichols, T. D. Nudds, W. R. Porath, and N. G. Tilghman. 1996. ARM! For the future: adaptive resource management in the wildlife profession. Wildlife Society Bulletin 24:436–442.

Lee, K. N. 1993. Compass and gyroscope: integrating science and politics for the environment. Island Press, Washington D.C., USA.

Matschke, G. H., D. S. deCalesta, and J. D. Harder. 1984. Crop damage and control. Pages 647–654 *in* L. K. Halls, editor. White-tailed deer: ecology and management. Stackpole Books, New York, New York, USA.

McShea, W. J., H. B. Underwood, and J. H. Rappole. 1997. The science of overabundance: deer ecology and population management. Smithsonian Institution Press, Washington D.C., USA.

Pierson, T. G., and D. S. deCalesta. 2015. Methodology for estimating deer impact on forest resources. Human–Wildlife Interactions 9:67–77.

Redding, J. A. 1995. History of deer population trends and forest cutting on the Allegheny National Forest. Pages 214–224 *in* Proceedings of the 10th Northcentral Hardwoods Conference. U.S. Forest Service Technical Report NE-197.

Rooney, T. P., and W. J. Dress. 1997. Species loss over sixty-six years in the ground layer vegetation of Heart's Content, an old-growth forest in Pennsylvania USA. Natural Areas 17:297–305.

Rooney, T. P., and D. M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. Forest Ecology and Management 181:165–176.

Rooney, T. P. 2010. What do we do with too many white-tailed deer? ActionBioScience news release. American Institute of Biological Sciences news release.

Stout, S. L., A. A. Royo, D. S. deCalesta, K. McAleese, and J. C. Finley. 2013. The Kinzua Quality Deer Cooperative: can adaptive management and local stakeholder engagement sustain reduced impact of ungulate browsers in forest systems. Boreal Environment Research 18:50–64.

SYSTAT 13. 2013. SYSTAT Software, Inc. Chicago, Illinois, USA.

Tilghman, N. G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. Journal of Wildlife Management 53:524–532.

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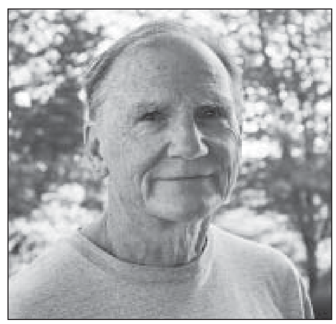

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