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# The Kinzua Quality Deer Cooperative: can adaptive management and local stakeholder engagement sustain reduced impact of ungulate browsers in forest systems?

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The Kinzua Quality Deer Cooperative (KQDC) was established in 2000 to test new approaches to stewardship of white-tailed deer and forest habitat on a 30 000 hectare landscape in northwest Pennsylvania, USA. Partners included land managers, scientists, educators, tourism promoters, and hunters. KQDC goals were adaptive management of the deer herd, improved habitat quality and deer herd attributes, and sustained hunter participation. The KQDC's tools included novel Pennsylvania Game Commission programs, habitat management, monitoring of deer and habitat, and hunter outreach. Over the first decade, deer densities in KQDC declined by 50%. Deer weight and antler characteristics improved. Browse impact on woody seedlings declined. Herbaceous indicator plants improved. The need to fence regeneration harvests declined. Hunter participation met KQDC goals for deer density and impact. The authors, research scientists and participants in the cooperative, report the results of this case study here including outcomes from ecological research and monitoring and observations of the KQDC itself.

## Introduction

Throughout the 20th century, white-tailed deer (*Odocoileus virginianus*) browsing threatened the sustainability of forest management throughout Pennsylvania, USA. Considerable evidence of impact on vegetation (Hough 1965, Marquis 1974, Tilghman 1989, McWilliams *et al*. 1995, Redding 1995, Rooney and Dress 1997, Horsley *et al*. 2003) and other wildlife (deCalesta 1994, Nuttle *et al*. 2011) was documented through research studies that included observations of change through time as well as exclosure and enclosure studies. These localized impacts mirrored similar evidence from research on forest ecosystems around the world (Gill 1992, Hobbs 1996, Fuller and Gill 2001, Russell *et al*. 2001, Wardle *et al*. 2001, Allombert *et al*. 2005, Martin *et al*. 2011). By 2000, forest managers routinely fenced regeneration harvests to exclude white-tailed deer, at considerable expense. For example between 1995 and 2003, the Pennsylvania Bureau of Forestry averaged over $750 000 per year on fence construction (Pennsylvania DCNR

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2005). Foresters, farmers, and conservationists (Gibbon 2001) argued that hunting regulations should be used to reduce deer impact, while many hunters held that high deer populations were essential to sustain the hunting heritage of Pennsylvania (Kosack 1995, Frye 2006). The result was sustained controversy generally directed at the Pennsylvania Game Commission (hereafter called the Game Commission).

In North America, wildlife are managed under a public trust doctrine (Riley *et al*. 2002, Organ *et al*. 2006) in which the government holds all wild animal resources in a public trust for current and future generations. In the United States, individual states are the primary level of government in charge of wildlife resources. In Pennsylvania, both the state constitution and the state's Game and Wildlife Code direct the Game Commission to "protect, manage, and preserve wildlife and their habitat within the Commonwealth for the benefit of all people, including generations yet to come " (Rosenberry *et al*. 2009). The public trust doctrine means that private landowners and managers of public land are dependent on the Game Commission for regulations to manage the impact of white-tailed deer on their habitat, and in turn, the Game Commission and hunters are dependent on land managers to sustain habitat essential to the well-being of the deer herd. Concurrently, hunters rely on the PGC to provide hunting opportunities through the sale of hunting licenses and regulations that govern hunting seasons and limits. In return, the Game Commission, a self-funded government commission, relies on hunter license fees as a principal source of income. Clearly, relationships among all three stakeholder groups are ultimately mediated by the Game Commission itself, through public comment at hearings, participation in Advisory Committees, and, to a lesser extent through political pressure exerted through the legislature. Thus, the relationship between land managers whose forest management goals are affected by deer browsing impacts and hunters who use their land for quality hunting opportunities has historically been tenuous and, at times, contentious (Frye 2006).

Controversy about deer management has a long history in North America and in Pennsylvania (Kosack 1995, Frye 2006). For decades, an alliance of northwestern Pennsylvania forest land managers and scientists worked in the Game Commission-centric framework to reduce negative deer impacts on forest regeneration, wildlife, and biodiversity. They co-sponsored research (e.g., Tilghman 1989, Horsley *et al*. 2003), tours, conferences (Cochran 1987, Horsley 1992), and frequently testified at public hearings. Success was at best limited and often short-lived (Frye 2006). At the Game Commission level, hunting interests who favored more deer usually prevailed, and while deer densities in 2000 were lower than historic highs (Redding 1995), impacts and controversy remained at challenging levels.

The Sand County Foundation, a non-governmental organization focused on Aldo Leopold's land ethic espousing "sound, voluntary environmentalism that depends on private ownership and stewardship" began to work on deer overabundance issues in Pennsylvania and elsewhere in the 1990s. Their concept of direct stewardship engagement with forests, wildlife, and stakeholders suggested an alternative to the completely Game Commission-centric approach. Thus, in 2000, a group of private landowners, public land managers, scientists, hunters, and others, with support and guidance from the Sand County Foundation, came together to form the Kinzua Quality Deer Cooperative (KQDC). The participants hoped that an active effort to build a site-specific, adaptive management (*sensu* Holling 1978 and Walters 1986) relationship between land managers and hunters who used their land could lead to a more sustainable and less contentious relationship (Fig. 1). Within this conceptual model of interdependence, land managers and hunters still depended upon the Game Commission to set regulations that would allow for a positive interaction. Land managers planned to provide more locally specific information and engagement opportunities for hunters, and adaptively implement state regulations based on monitoring local conditions. To this end, the land managers designated 30 000 contiguous hectares in northwestern Pennsylvania as the KQDC land base (Fig. 2). This acreage was large enough to incorporate many landowners and also large enough that edge effects on the deer herd itself would not overwhelm the responses to adaptive management of the herd on the KQDC

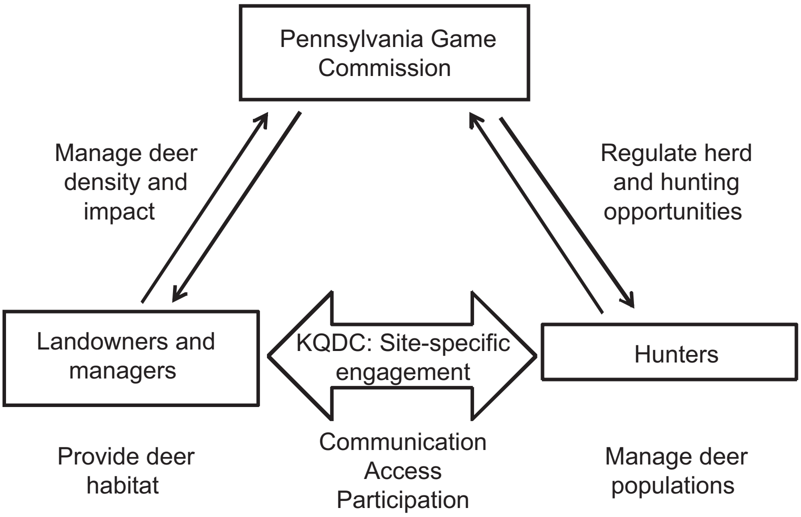


**Fig. 1**. Model of interdependence among the various stakeholders interested deer-forest management within the Commonwealth of Pennsylvania. This model recognizes that both land managers and hunters still depend upon the Game Commission to set regulations to would allow for positive interactions, but emphasizes that the implementation of the regulations would be planned to provide more locally specific information and engagement opportunities between the landowners and hunters.

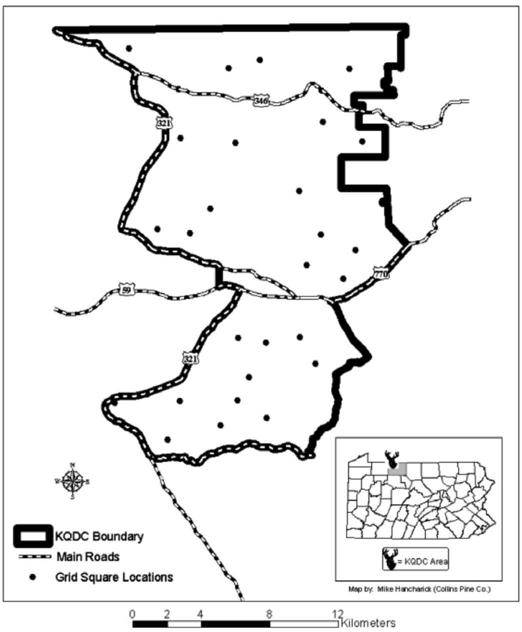


**Fig. 2**. Map of the Kinzua Quality Deer Cooperative Area (KQDC).

itself. For example, Tierson *et al*. (1985) found that a median home range size for white-tailed deer in the nearby Adirondack region of the northeastern US was less than 300 ha. The KQDC Leadership Team planned to use regulations and deer management programs available from the Game Commission in a common, democratically and scientifically unified effort to achieve four goals: local engagement and adaptive management of the KQDC deer herd, improved habitat quality, improved deer herd attributes, and sustained hunter engagement. For purposes of this paper, we define local engagement and adaptive management as (1) sustained participation and in-kind contributions to KQDC management, and (2) evidence of use of monitoring data to adapt management strategies. We define improvements in habitat quality as (1) reduced browsing pressure on desirable tree regeneration; (2) increased abundance, size, and improved reproductive status of the understory plant community; and (3) reduced need to fence regeneration harvests. We define improved deer herd attributes as (1) reduced deer density, and (2) increased deer and antler size. We define sustained hunter engagement by (1) opportunities and incentives created for hunters to become engaged in the adaptive management of the KQDC, and (2) sustained hunter participation in KQDC hunting opportunities.

The tools for the KQDC included novel programs offered by the Game Commission, an aggressive habitat management program, intensive monitoring of deer and understory vegetation, and intensive hunter outreach. This paper reports on a case study basis the efforts undertaken by the cooperative to achieve its objectives and reports on the success of these efforts. Three of the authors were members of the KQDC leadership team from its inception (Stout, deCalesta, McAleese. Royo joined the KQDC Leadership Team later) and four of us have conducted research studies on the cooperative (Stout, Royo, deCalesta, Finley). Thus this paper provides an overview of the KQDC case study from a perspective like that of participatory action research (PAR, *sensu* McIntyre 2008). We are both observer/researchers and members of the cooperative, though unlike most participatory action research, we did not see ourselves in the dual role from the beginning of the project, as we focused on establishing the ecological monitoring programs and participated with the group in planning activities to keep hunters engaged.

## Material and methods

### Study site

The KQDC is located in the northwestern portion of the state of Pennsylvania, USA. It is within the unglaciated Allegheny High Plateau Section of the Appalachian Plateau Province (McNab and Avers 1994) with an average elevation of 613 m (range: 494–689 m). The major land managers are the Allegheny National Forest, Forest Investment Associates, the Collins Pine Company, Ram Forest Products, and the Bradford, PA, Municipal Watershed Authority. The landscape is dominated by contiguous forest, including mixed oak, northern hardwood, and Allegheny hardwood forest types, most of it 80–100 years old. Major species include *Prunus serotina, Fagus grandifolia, Acer saccharum, Acer rubrum, Betula lenta* and *alleghaniensis, Acer pensylvanicum, Fraxinus americana, Tsuga canadensis* and *Quercus rubra*. The area is well-roaded, with road densities and quality varying by ownership and management objectives. The entire area is open to public hunting, and in addition to hunting and forest management activities of the managing organizations, the area is used for a variety of other recreation activities, and for development of subsurface oil and gas resources.

### Local engagement and adaptive management

A Leadership Team consisting of representatives from each land management organization, the Sand County Foundation, the Pennsylvania State University Forest Extension Service, the Game Commission, the Allegheny National Forest Vacation Bureau, local hunters, outdoor writers, and the USDA Forest Service Northern Research Station made decisions about management, monitoring, and hunter engagement activities. Participants shared leadership informally, and foundation funding supported a wildlife biologist (deCalesta) who coordinated annual deer and some vegetation monitoring activities and provided annual reports and input to Leadership Team decisions such as the number of additional antlerless permits to request. Participants provided funding in a mix of in-kind services and cash contributions, and the group also received several foundation grants. In 2010, the Sand County Foundation convened an independent review team to evaluate the accomplishments of the KQDC project and provide recommendations for future development.

McLain and Lee (1996) use the Halbert (1993) summary of adaptive management as “the application of experimentation to the design and implementation of natural-resource and environmental management policies.” The KQDC Leadership team intended to apply data gathered through research and monitoring of deer and habitat on the KQDC to design and implement locally specific management policies. Specifically, the Leadership Team planned to inform annual requests for additional antlerless deer permits with data about deer density and browsing pressure on vegetation.

### Habitat quality objective

#### Browse impact

In 2000, the KQDC Leadership Team overlaid a grid pattern on a map of the KQDC landscape. The grid squares were 2.6 km$^2$, and 26 of the resulting squares were selected at random for several data collection efforts. The same grid squares were used in data collections efforts each year. As personnel collected pellet group data during the spring (*see* below), they collected data on deer browse impact on tree seedlings at alternate pellet group sample plots (i.e., 1.2 m circular plots every 60 m along each 1.6 km pellet transect). Deer impact data were obtained by characterizing browsing on six tree seedling species. A scoring system from 1–5 was used, where 1 = no browsing, 2 = 0%–50% of stems are browsed, 3 ≥ 50% of stems browsed, 4 ≥ 50% of stems browsed and twigs browsed down to main stem, and 5% to > 50% stems browsed, few twigs, and terminal leader is browsed to < 15 cm. The six target species are *F. grandifolia*, *A. pensylvanicum*, *A. rubrum*, *P. serotina*, *Betula* spp. (*Betula lenta* and *alleghaniensis* are difficult to distinguish as seedlings, so both were lumped into a "*Betula*" category), and *T. canadensis*.

## Understory plant abundance, size and reproductive status

Northern hardwood forests are advance-regeneration dependent (Marquis and Johnson 1989). Advance regeneration abundance increases as deer density decreases (Horsley *et al*. 2003, Tilghman 1989), as do the size and reproductive status of many indicator plants (reviewed by Kirschbaum and Anacker 2005). We assessed changes in understory plant abundance, size, and reproductive status on plots in the unmanaged, mature portion of the forest. We restricted our sampling to areas lacking recent natural or anthropogenic disturbance as the biotic and abiotic changes caused by disturbance alter plant community dynamics and often interact with deer browsing (Tripler *et al*. 2005, Kreuger *et al*. 2009, Nuttle *et al* 2013).

Within each selected 2.6 km$^2$ grid square we nested seven 35.4 × 35.4 meter (1250 m$^2$) permanent vegetation monitoring plots within forest stands beginning in 2001. One plot was centered within the overall 2.6 km$^2$ grid square and up to six others radiated out 400 meters from the center point at 60° intervals beginning with a randomly chosen azimuth. Five entire grid squares were dropped following the initial survey as forest conditions did not meet the objective of understanding deer-forest dynamics in mature, unmanaged northern hardwood forests (i.e., herbicided, harvested, sapling/pole-sized, or *Quercus* spp. dominated stands were dropped) leaving a total sample of 147 monitored stands (21 squares × 7 stands = 147). Over time, 16 individual monitoring plots were lost through timber management and/or oil and gas resource extraction activities.

At each permanent vegetation monitoring plot we censused the density, by species, of all established woody seedlings (≥ 0.3–1.5 m) on four, 2 m radius (12.54 m$^2$) subplots located at the corners of the overall plot in 2001, 2003, 2007, and 2011. Additionally, we collected detailed morphological and demographic data on three liliaceous herb species reported to be sensitive to deer browse (reviewed by Kirschbaum and Anacker 2005): *Trillium* spp. (includes *T. erectum*, *T. undulatum*, and *T. grandiflorum*), *Maianthemum canadense*, and *Medeola virginiana*, considered a potential indicator in Pennsylvania (Diefenbach and Fritsky 2007). For *Trillium* spp., we recorded the proportion of stems in three distinct demographic stages (one-leafed individual, three-leaf non-reproductive, three-leaf reproductive; Knight 2004) and height of individuals located throughout the entire 1250 m$^2$ plot in each census period. For *M. canadense*, we recorded longest leaf length (cm) of individuals in four, 1-m radius subplots nested within the larger woody subplot in all four census periods. Finally, for *M. virginiana* in 2003, 2007, and 2011 we recorded stem heights of individuals along a 2 × 50 m belt transect running through the plot from north to south.

To test how vegetation metrics collected on permanent plots changed over time, and more specifically, whether these metrics differed in the census periods following deer herd reductions, we used repeated measures general linear mixed modeling in SAS (SAS Institute Inc. 2011). We treated each plot nested within grid squares as a random factor with year as the fixed effect. Analyses used the restricted maximum likelihood estimation method and denominator degrees of freedom were calculated using the Kenward–Rogers adjustment (Littell *et al*. 2006). For analyses on seedling densities, we modeled the data using a gamma distribution with a log-link function. This distribution is appropriate for continuous, non-negative data that exhibits overdispersion (Bolker 2008). The proportion of *Trillium* population in reproductive status was modeled using arc-sine squared root transformation. All other metrics were normally distributed.

When significant differences were detected in the overall test, differences among means were tested using Tukey's HSD test (PDIFF ADJUST = TUKEY, Littell *et al*. 2006).

### Fencing, regeneration harvests and outcomes

As noted above, there was no formal assessment of regeneration harvest practices, acres under fence, or landowner/manager assessment of regeneration harvest practices during the first decade of KQDC implementation. However, e-mail queries of land managers provided some anecdotal data about the proportion of the KQDC in early age classes and manager expenditures on fencing in general and in the KQDC in particular near the end of the first decade. We present these results here without analysis for purposes of completeness.

## Herd attributes

From 2001–2010, the Game Commission instituted a two-week concurrent rifle season for both antlered and antlerless deer, at first statewide. The prior regulation in Pennsylvania was a two-week antlered-only rifle season followed by a three-day antlerless season. In 2002, the Game Commission instituted statewide antler restrictions, requiring hunters without an antlerless permit to limit their harvests to deer with at least 3 points on each side in the KQDC region. In 2003, the Game Commission initiated a Deer Management Assistance Program (DMAP) statewide under which managers of large blocks of land who showed that deer were interfering with achievement of their management objectives could request that the Game Commission provide additional antlerless licenses to hunters on their property. The Game Commission designed the DMAP program as a mechanism for managers to achieve fine-scale deer management goals within the coarse-scale wildlife management units. The Game Commission set seasons and bag limits at the wildlife management unit scale; these have a mean area of about 540 000 ha. Under the DMAP program, land managers requested and distributed DMAP coupons to hunters, who, in turn, sent them to the Game Commission to receive the additional permits.

From the beginning, the KQDC Leadership Team practiced adaptive management, using DMAP as its primary tool to achieve its objectives. In the absence of detailed information and a management plan, DMAP, by default, provided one additional antlerless permit per 20 ha. The KQDC Leadership Team developed a detailed management plan that targeted a deer density of about five deer km$^{-2}$ based on earlier research conducted in the region (Tilghman 1987, Horsley *et al*. 2003). They then used data from deer and deer impact monitoring to guide annual requests for DMAP coupons.

Land managers also recognized that providing early successional forest habitat through timber harvesting was important for providing forage for deer across the KQDC landscape. Provision of this habitat was not formally coordinated, but informal conversations among members of the Leadership Team and with volunteers ensured a common understanding of the level of habitat provided.

### Deer density

Every spring, trained personnel of KQDC membership organizations conducted pellet-group counts on each of the 26 selected grid squares, following the technique described by deCalesta (2013). Within each selected grid square, pellets were tallied in 1.2 m circular plots every 30 m along five 1.6 km transects. In addition to these data, volunteers and personnel of KQDC membership organizations also conducted yearly counts of deer along six roadside routes established at the beginning of the study. These data helped managers estimate annual recruitment.

### Deer and antler size

The KQDC Leadership Team operated voluntary check stations for harvested deer for several days each year during the concurrent two-week rifle season. The number of check stations and the days of operation varied from year to year, but the measurements taken by those staffing the check stations were consistent. Both antlered and antlerless deer were checked. Experienced wildlife biologists trained personnel staffing the stations to estimate deer age using tooth wear estimates. Check station staff also recorded the hunter's estimation of where the deer was harvested, the weather when and where it was harvested, the hunter's state, county, and town of residence, license type and number, and sex, age, girth, weight, antler points, spread and beam diameter of deer.

### Hunter engagement

#### Hunter engagement opportunities and incentives

The KQDC Leadership Team planned a variety of activities to engage hunters in adaptive management of the KQDC and to share data and information about the KQDC effort with hunters and potential hunters. These activities were part of the adaptive management strategy, as all participants in the KQDC recognized that continued hunter participation on KQDC was vital to the demonstration's success. Specifically, hunters were invited to join the leadership team, were offered annual training in the pellet-group technique for estimating deer density, and were among the volunteers who conducted roadside counts. Results of KQDC monitoring efforts were posted as annual reports on the KQDC web site, and reported through news releases and presentations.

From 2001 to 2011, Sand County Foundation and the KQDC Leadership Team hosted an annual banquet, complete with raffles of hunting equipment, at which a keynote speaker presented information on deer biology and a KQDC Leadership Team member provided an update on deer density, deer characteristics and habitat quality across the KQDC. Banquet tickets were offered below cost to hunters on the KQDC mailing list, and raffle tickets were given to those who brought deer to the check station — one ticket for each antlered deer and two for each antlerless deer. The explicit idea was to thank hunters for the ecological service that their hunting provided, while simultaneously providing information about KQDC. The mailing list developed through the DMAP coupon process was used to inform hunters about the banquet each year.

#### Sustained hunter participation

The Sand County Foundation contracted with scientists at the Pennsylvania State University Human Dimensions Unit to design and conduct a survey of hunters associated with KQDC. Luloff and others surveyed hunters in the KQDC and surrounding area at the beginning of DMAP. (Luloff *et al*. 2006, Ward *et al*. 2008). Their questions, informed by a focus group with KQDC leadership, assessed attitudes towards DMAP, antlerless deer hunting, concurrent seasons, and reductions in deer density. These questions helped KQDC leadership understand factors that motivated continued hunter participation in KQDC hunting opportunities.

## Results and discussion

### Local engagement and adaptive management

#### Sustained participation and in-kind contributions

One measure of success of KQDC management is continued voluntary participation in its Leadership Team and activities. The KQDC Leadership Team sustained a complex program of adaptive deer management, deer and vegetation monitoring, and stakeholder and policy-maker outreach through a full decade of activities. Pellet group transects were tallied, deer check stations staffed, DMAP requests submitted on time, DMAP coupons mailed to applicants, tours conducted, and banquets hosted annually. Intensive vegetation surveys were conducted in 2001, 2003, 2007, and 2011, funded by a mix of foundation and stakeholder resources. Stakeholders contributed an average of more than 800 hours of in-kind services to collect pellet group data, conduct roadside counts, accept and process DMAP coupon requests, and staff check stations annually. The local tourism agency placed road signs directing people to the administrative site for the KQDC, which was staffed in-kind by employees of the Allegheny National Forest.

## Adaptive management

In 2001, the KQDC Leadership Team submitted a deer management plan, providing narrative and early quantitative evidence of negative deer impact on forest regeneration and targeting a goal density of five deer km$^{-2}$. The first round of pellet group counts on the KQDC indicated that deer density averaged nearly 11 deer km$^{-2}$, so the KQDC Leadership Team requested one DMAP coupon per 10 ha, or 3000 coupons. This was twice the default rate established by the program. Each year, data from the spring pellet group counts (informed by the previous year's roadside counts to provide an estimate of deer recruitment) were used to estimate the current density and thus inform the yearly coupon requests. DMAP required intensive land manager involvement. Land managers publicized availability of DMAP coupons, managed hunter requests for coupons, and mailed out the coupons to hunters. Hunters then had to submit the coupons to Game Commission for actual antlerless permits. Each year, 80% of coupons were converted to antlerless permits. Across years, DMAP coupon requests varied by an order of magnitude (Table 1). However, even during years when deer density was estimated to be at or near the goal density, the Leadership Team continued to offer DMAP coupons at greatly reduced numbers to reward loyal KQDC hunters with continued hunting opportunities. During the first decade of operation of the KQDC, the number of antlerless permits offered in the wildlife management unit of which KQDC is a part (the KQDC occupies 0.05% of its wildlife management unit) varied from 13 000 to 44 000.

The 2010 Independent Review Team lauded the KQDC Leadership Team "for the considerable effort of bringing together, creating ownership of, and incorporating the objectives of a diverse group of stakeholders toward development of an alternative deer management paradigm […] Results to date clearly indicate that an innovative stakeholder-driven management plan can achieve: lowered deer densities, enhanced regeneration success, improved deer condition (age-specific antler development and body weights), and a gradual recovery of herbaceous understories." The team recommended wider dissemination of the results of the KQDC demonstration, focusing on interested publics, policy makers, and the scientific community. They also recommended efforts to increase the representation and participation of hunters in the cooperative's leadership. They urged continuation of the detailed monitoring, further study of KQDC hunters, and increased coordination of vegetation management to ensure a stable supply of early successional habitat (K.V. Miller, Kinzua Quality Deer Cooperative, unpubl. data).

As the first decade of KQDC operations drew to a close, participants in the Leadership Team began work on strategies to address the suggestions of the independent review team. Members began a process of voluntary contributions to sustain the cooperative's activities. Informal cooperation on vegetation management continued.

The continued commitment to KQDC participation demonstrated by landowner willingness to self-assess a per-acre fee suggests that

**Table 1**. Changes in deer populations and additional hunting pressure over time. Deer densities (deer km$^{-2}$) represent averages (± SE) across all sampled grid squares using pellet group surveys as well as the 95% confidence intervals. DMAP refers to the number of additional antlerless coupons (Deer Management Assistance Program) issued for the KQDC in the preceding fall.

| Year | *n* | Mean ± 1 SE | 95% CL | DMAP coupons |
|---|---|---|---|---|
| 2002 | 24 | 10.54 ± 1.03 | 8.41–12.66 | 0 |
| 2003 | 24 | 11.07 ± 0.95 | 9.1–13.05 | 0 |
| 2004 | 24 | 9.55 ± 0.77 | 7.95–11.15 | 3000 |
| 2005 | 26 | 5.55 ± 0.63 | 4.26–6.85 | 3000 |
| 2006 | 26 | 4.47 ± 0.52 | 3.4–5.55 | 700 |
| 2007 | 26 | 4.7 ± 0.44 | 3.81–5.6 | 150 |
| 2008 | 26 | 5.76 ± 0.66 | 4.4–7.12 | 300 |
| 2009 | 26 | 5.93 ± 0.62 | 4.66–7.21 | 550 |
| 2010 | 26 | 5.88 ± 0.78 | 4.28–7.48 | 800 |
| 2011 | 24 | 6.65 ± 0.83 | 4.93–8.37 | 800 |
| 2012 | 26 | 3.74 ± 0.35 | 3.02–4.45 | 800 |

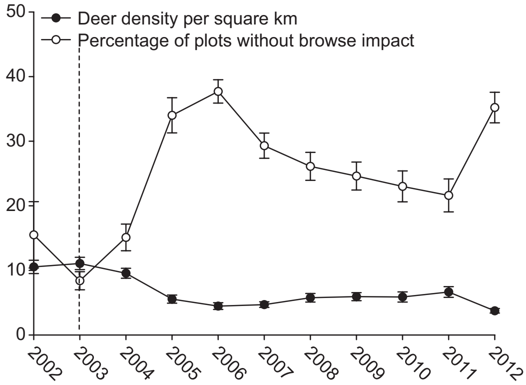


**Fig. 3**. Change in mean (± 1 SE) deer densities and percentage of plots with zero browse observed on seedlings of *F. grandifolia*, *A. pensylvanicum*, *A. rubrum*, *P. serotina*, *Betula* spp., and *T. canadensis* over time.

for the land managers, scientists, local agency personnel, tourism officials, outdoor writers, and others, the KQDC case study of site-specific stakeholder engagement was achieving its objectives of improving habitat, improving deer herd attributes, and sustaining hunter engagement and participation.

The KQDC effort continues. The KQDC Leadership Team continues to collect monitoring data and use it to set DMAP coupon requests. Additional research efforts include a detailed study of the relationship between landscape heterogeneity, deer density, and deer impact, a study of the governance structure of KQDC as a novel example of governance of common pool resources (Ostrom 1990), and a related study that will re-survey KQDC hunters.

## Habitat quality

### Browse impact

As deer densities declined there was a concomitant decline in browsing on woody seedlings. The percentage of plots from the pellet-group surveys with no browse impact on the six targeted woody species responded inversely to changes in deer density, increasing as deer populations decreased, and decreasing in years when deer densities increased (Fig. 3). *Fagus grandifolia* seedlings were the most likely to show zero to light impact, followed by *A. pensylvanicum*, *P. serotina*, *Betula* spp., *A. rubrum* and *T. canadensis*. The rank order browsing tracks reported tree seedling species palatability to white-tailed deer (Bramble and Goddard 1953, Healy 1971, Horsley *et al*. 2003).

### Abundance, size, and reproductive status of understory plants

For all three liliaceous indicator species, morphological and reproductive metrics improved over time with most increasing significantly only following deer herd reductions in fall of 2003 (Table 2). By 2011, the average height of *Trillium* spp. increased by 40%–66% and the proportion of reproductive individuals more than doubled (Table 2). By 2011, *M. canadense* average leaf length was significantly greater than at any time prior to deer herd reductions, expanding by 19%–35% (Table 2). Finally, *M. virginiana* heights were nearly 100% greater in 2011,

**Table 2**. Generalized linear mixed model results of herbaceous indicator metrics over time in the Kinzua Quality Deer Cooperative (KQDC) project. For each metric we present the untransformed means ± 1 SE. Different subscript letters indicate significant ($p < 0.05$) differences between means within a metric.

| | *Trillium* spp. | | *M. canadense* | *M. virginiana* |
|---|---|---|---|---|
| Predictors | Height (cm) | Flowering (%/100) | Leaf length (cm) | Height (cm) |
| Year | $F_{3,164}$ = 38.99, $p < 0.0001$ | $F_{3,165}$ = 11.37, $p < 0.0001$ | $F_{3,78.9}$ = 23.83, $p < 0.0001$ | $F_{3,78.5}$ = 49.28, $p < 0.0001$ |
| 2001 | 10.2 ± 0.86[a] | 0.09 ± 0.05[a] | 3.7 ± 0.10[a] | – |
| 2003 | 12.1 ± 0.50[a] | 0.08 ± 0.02[a] | 4.2 ± 0.12[ab] | 7.3 ± 0.28[a] |
| 2007 | 17.7 ± 0.59[b] | 0.21 ± 0.03[b] | 4.6 ± 0.11[b] | 9.9 ± 0.46[b] |
| 2011 | 17.0 ± 0.43[b] | 0.21 ± 0.03[b] | 5.0 ± 0.13[c] | 14.50 ± 0.77[c] |

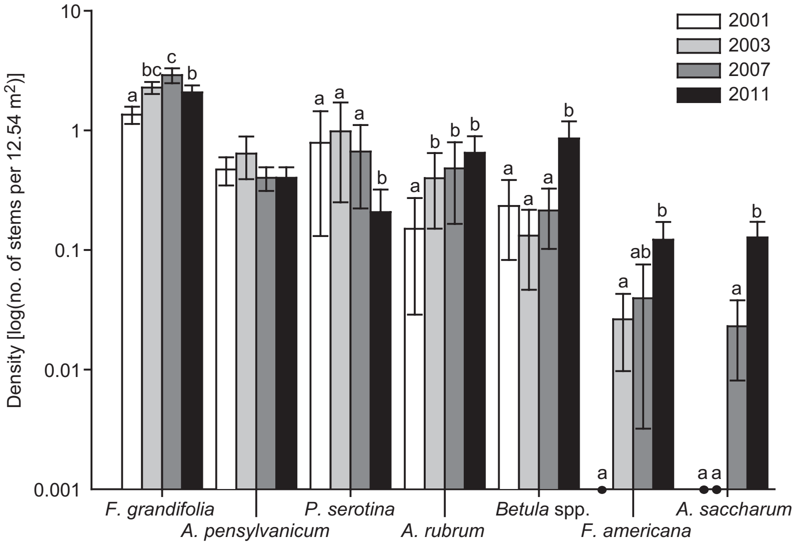


**Fig. 4**. Established seedling (≥ 0.3 to < 1.5 m) densities in the permanent vegetation monitoring plots of the Kinzua Quality Deer Cooperative (KQDC) project in all four census periods. Densities are expressed in number of stems per 12.54 $m^2$ on a $\log_{10}$ scale. Different superscripts denote significantly different ($p < 0.05$) seedling densities over time within a species. For *F. americana* and *A. saccharum*, dots on the *x*-axis denote years with zero seedlings.

relative to 2007 (Table 2). Our results on these three taxa are consistent with prior work demonstrating the sensitivity of these morphological and demographic metrics to deer browse pressure (Rooney 1997, Augustine and Frelich 1998, Knight 2003, Webster *et al*. 2005; reviewed by Kirschbaum and Anacker 2005).

By 2011, browse-sensitive woody species all experienced significant increases in stem densities into the established seedling size class (Fig. 4). These increases in abundance occurred regardless of whether species were shade-intolerant (*F. americana,* $F_{3,224.5} = 3.54$, $p = 0.016$), intermediately shade-tolerant (*A. rubrum*, $F_{3,224.1} = 4.97$, $p = 0.002$; *Betula* spp., $F_{3,224.3} = 4.32$, $p = 0.006$) or shade-tolerant (*A. saccharum*, $F_{3,299} = 8.23$, $p < 0.0001$). Moreover, seedling densities of *A. saccharum*, *Betula* spp. and *F. americana* were significantly greater in 2011 than in either census period prior to deer herd reductions (Fig. 4). In contrast, dynamics of browse-tolerant species were inconsistent over time (Fig. 4). Shade-tolerant species either displayed no change over time (*A. pensylvanicum,* $F_{3,224.3} = 1.03$, $p = 0.38$) or experienced increases in abundance that predated herd reductions followed by a decline (*F. grandifolia,* $F_{3,224.1} = 11.03$, $p < 0.0001$; Fig. 4). Finally, densities of the shade-intolerant *P. serotina* declined by 73% by 2011 ($F_{3,224.1} = 4.36$, $p = 0.005$; Fig. 4). These results suggest that overbrowsing masks growth responses and ultimately alter recruitment hierarchies in to larger size classes, particularly for browse-sensitive species (Horsley *et al*. 2003, Long *et al*. 2007, Krueger *et al*. 2009). Despite the observed growth response in several species, forest understories throughout the KQDC remained dominated by *F. grandifolia*. Unmanaged, the presence of this dense, nearly monodominant recalcitrant understory layer will greatly constrain the future responses to tree and herbaceous recruitment and growth, potentially altering forest dynamics (reviewed by Royo and Carson 2006).

## Fencing, regeneration harvests and outcomes

Fencing of regeneration harvests within the region, along with their associated construction and maintenance costs, dropped precipitously beginning in 2003 as land managers anticipated the success of DMAP deer harvests (Fig. 5). The Collins Pine Company, one of the participating land managers of the KQDC, saw their average area requiring fencing within KQDC drop from 52.2 ha $yr^{-1}$ to zero following the deer culls. Concomitantly, the fencing costs dropped from \$22 712 $yr^{-1}$ to zero (N. Karger pers. comm.). The Allegheny National Forest stopped erecting fences within the KQDC area during the project

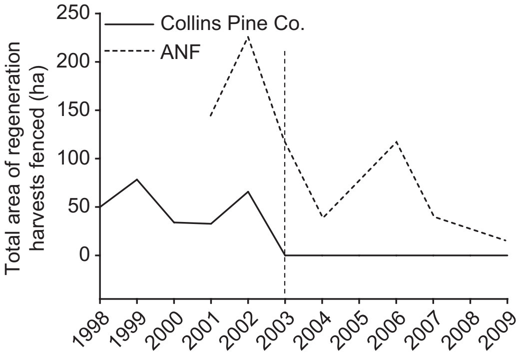


**Fig. 5**. Area fenced by two KQDC land managers over time. Figures for the Collins Pine Company reflect areas within the KQDC boundary. Allegheny National Forest (ANF) figures reflect area fenced throughout the National Forest, including areas within the KQDC.

period (A. Hille pers. comm.). These figures do not reflect the added fence maintenance costs that typically range from \$37 to \$50 $ha^{-1}$ $yr^{-1}$. Some cost reductions occurred region-wide as managers of large landholdings implemented the DMAP program on other portions of their ownership. For example, the Allegheny National Forest saw fencing of regeneration harvests drop across the 208 000 ha land base from 161.9 to 51.8 ha $yr^{-1}$.

During the first decade of the KQDC Project, the private land partners created about 4500 ha of early successional habitat through operational timber management harvests, seizing the opportunity created by the reductions in deer density and deer impact. During this time, as well, the Allegheny National Forest conducted an environmental analysis for the Sugar Run project, an area of 4696 ha within the KQDC area, reaching out to hunters specifically for input to plan development (Reitz *et al*. 2004). Implementation of this project added approximately 250 ha of additional early successional habitat late in the decade.

When assessed in their entirety, the data strongly suggest that reductions in deer density were associated with reductions in browsing impact on the understory plant community. Herbaceous indicator plants responded most dramatically, while increases in seedling abundance and size across the area were slower to develop, especially within those portions of the area in which no silvicultural manipulations took place (Royo *et al* 2010). In areas where silvicultural manipulations provided additional light to the forest floor (e.g., overstory harvests, herbicide control of recalcitrant layers), land managers were able to conduct regeneration harvests with less or no fencing resulting in a substantial cost savings.

## Herd attributes

### Deer density

Estimated over-winter deer densities declined over time, but only following the implementation of the DMAP program in fall 2003 (Table 1; Fig. 3). From 2005 to 2012, deer populations averaged 5.3 deer $km^{-2}$, which represents a 50% decline in population densities relative to the herd levels prior to the KQDC program. Population estimates derived from roadside counts were consistently well-correlated with population estimates derived from pellet group counts D.S. (deCalesta unpubl. data).

### Deer and antler size

Body weight of deer that hunters brought to check stations showed an upward trend, as did the antler characteristics of male deer (Table 3). As the sample was biased by hunter self-selection we have not conducted a statistical analysis. Regardless, body weights of deer varied by sex and age with the greatest gains recorded in fawns (24% and 44% in female and male fawns, respectively) and the lowest gains in yearlings (5% and 7% in female and male fawns, respectively). Antler characteristics of adult deer (≥ 2.5 yr) increased by 22%–28% (Table 3). The substantial increases in fawn weight bode well for future hunters. Vreeland *et al*. (2004) studied survival of radio-collared fawns in one forested and one agricultural landscape in Pennsylvania and found that along with broad habitat type, fawn weight at time of capture was the best predictor of survival. Shultz and Johnson (1995) found that for male fawns, greater body weight at birth was significantly positively correlated with greater body weight at 1.5, 2.0 and 2.5 years.

Thus, over its first decade, the KQDC program did result in decreases in deer abundance across the KQDC project area, while the average weight and antler characteristics of deer brought to check stations over the same time period increased. With a local program to monitor deer abundance and deer attributes, the KQDC Leadership Team was able to use the DMAP program to achieve locally specific density targets on an area substantially smaller than the wildlife management unit within which PGC planned its own management of the deer herd and deer hunting opportunities

## Hunting experience

### Hunter engagement and incentives

Hunter engagement in the KQDC was initially high and declined over time. The Leadership Team sponsored periodic public meetings to inform hunters about the plans for KQDC, invite their participation in the Leadership Team, and share KQDC results and progress. The first meeting drew a very large crowd to a local university, but later meetings were poorly attended. Similarly, several hunters participated in early Leadership Team meetings but their participation was not sustained through the full first decade. The number of hunters bringing deer to check stations decreased relatively steadily throughout the decade. Volunteers were solicited and trained to participate in the roadside counts, and the small group who conduct this activity was very consistent in its participation and reporting. In addition, for several years, members of the KQDC Leadership Team offered workshops entitled "Deer density and carrying capacity." Enrollment in these local workshops declined after 2005, therefore members of the KQDC Leadership Team facilitated the development of the workshops in other locations throughout Pennsylvania and New York.

Each year the banquet and raffle drew more than 100 hunters and other KQDC volunteers. In 2001, many attendees were hunters, including some who came from as far as 500 km away. By 2011, the banquets were attended primarily by hunters and volunteers from the local area. Some hunters reported anecdotally that the banquets were an important reason they continued to hunt the KQDC.

### Sustained hunter participation

The Penn State study of hunter attitudes was conducted in winter of 2004, after the first hunting season in which DMAP coupons were available in Pennsylvania but before the density reductions that resulted from of KQDC's aggressive use of DMAP to reduce the size of the KQDC deer herd.

**Table 3**. Mean white-tailed deer body weight and antler characteristics over time.

| Metrics | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | Increase (%) 2001–2010 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Female** | | | | | | | | | | | |
| Weight (kg) | | | | | | | | | | | |
| Fawns[1] | 22.5 | 26.0 | 24.6 | 25.4 | 29.5 | 27.0 | 26.1 | 26.2 | 28.0 | – | 24.44 |
| Yearlings[2] | 40.5 | 39.4 | 37.7 | 38.5 | 40.6 | 42.4 | 45.4 | 45.6 | 41.2 | 42.6 | 5.19 |
| Adults[3] | 44.8 | 42.0 | 42.9 | 44.7 | 46.8 | 46.4 | 44.8 | 49.7 | 49.7 | 49.0 | 9.38 |
| **Male** | | | | | | | | | | | |
| Weight (kg) | | | | | | | | | | | |
| Fawns[1] | 25.8 | 26.2 | 26.2 | 30.8 | 29.8 | 32.6 | 31.5 | 33.0 | 31.6 | 37.2 | 44.19 |
| Yearlings[2] | 43.4 | 44.9 | 44.1 | 41.5 | 47.2 | 47.4 | 49.1 | 50.2 | 48.2 | 46.3 | 6.68 |
| Adults[3] | 52.0 | 53.8 | 55.0 | 55.9 | 47.2 | 59.8 | 61.6 | 60.2 | 64.1 | 60.6 | 16.54 |
| Antler points[3] | 6.2 | 7.6 | 7.1 | 6.7 | 7.6 | 8.1 | 7.7 | 7.4 | 7.8 | 7.7 | 24.19 |
| Spread (cm)[3] | 30.0 | 38.4 | 34.5 | 33.5 | 37.6 | 37.1 | 35.8 | 37.8 | 38.0 | 36.6 | 22.00 |
| Beam diameter (mm)[2] | 23.6 | 27.8 | 26.1 | 25.0 | 22.9 | 28.3 | 28.3 | 29.7 | 28.4 | 30.1 | 27.54 |

[1)] ≤ 1 yr olds, [2)] 1.5 yr olds, [3)] ≥ 2.5 yr olds.

Luloff *et al*. (2006) found that 57% of hunters surveyed hunted in the KQDC regardless of additional opportunities to harvest antlerless deer, while 43% of those surveyed were hunting in the KQDC specifically in response to the increased antlerless allocations available in 2003 through the DMAP program. Eighty percent of the DMAP hunters had harvested an antlerless deer in 2003 as compared with 67% of traditional hunters, and DMAP hunters had harvested more antlerless deer in 2003 (1.78 compared with 1.29 for traditional hunters). They were more likely to purchase additional antlerless licenses in the future. DMAP hunters were also more likely to support continuation of concurrent antlered and antlerless seasons than traditional hunters.

On the other hand, DMAP hunters reported a lower likelihood than traditional hunters to continue hunting in KQDC, and specifically a lower likelihood should they find fewer deer in the future. Traditional hunters had hunted in the KQDC for more years preceding the advent of KQDC and new regulations, were more likely than DMAP hunters to be affiliated with a camp in the area, and were more likely to continue hunting the area in the future. As the authors of the study summarized their results, “In short, the real challenge to KQDC managers may not be in reducing deer populations, but maintaining them at desired levels. Such maintenance will likely fall on the shoulders of Traditional hunters, reflecting their continued presence in the KQDC through camp membership, social ties, and long-term fidelity.” Overall, the available evidence on hunter engagement bears out Luloff and colleagues’ prediction: hunters are adapting to the changed conditions of the herd, the habitat and the hunt and sustain a long-term commitment to this particular area. Specifically, hunters continue to seek KQDC DMAP permits and to hold the herd at or near target levels (Table 1). We did not measure the degree to which measured improvements in deer characteristics have contributed to their loyalty.

## Conclusion

The KQDC project is, to our knowledge, the most comprehensive landscape-level adaptive management study of white-tailed deer impacts on forests communities in North America. Here, the investment in repeated monitoring of multiple metrics including deer populations, browse impact, forest understory plant communities, and hunter attitudes and engagement provide the KQDC Leadership Team with the information necessary to iteratively adapt the management of the deer and forest resources. The project also demonstrates that the DMAP program can achieve the objectives for which it was created, allowing KQDC land managers to achieve specific, targeted fine-scale goals for deer density and impact within the fluctuations in coarse-scale management of a much larger wildlife management unit. Thus far, the data strongly suggest this approach has succeeded in reducing browsing pressure on and increasing the abundance of advance regeneration; improving the size, abundance, and reproductive status of understory indicator plants; eliminating the need for fencing of regeneration harvests, and increasing deer weight and antler characteristics. Results on sustained hunter engagement were mixed. Hunters continued to use DMAP permits and kept deer densities within target levels; however, hunter engagement attending Leadership Team meetings, bringing deer to check stations, and participating in pellet count surveys was not sustained.

The KQDC Leadership Team relied completely on tools that were technically available to all: DMAP, check stations, roadside counts, pellet counts, and browse surveys. Other managers in the state used some of these tools as well, but no other managers used all the tools in an adaptive context. Specifically, even the KQDC landowners used DMAP default rates on other portions of their landholdings, and no other land managers used check stations, hunter incentives, or roadside counts. Other participants in DMAP maintained their coupon allocation at the default level for as long as landholdings were in DMAP, rather than adapting applications based on research and monitoring data. The Pennsylvania Department of Conservation and Natural Resources is currently pilot-testing an adaptive management approach to DMAP based in part on input from KQDC leaders.

As the KQDC project matures, continued monitoring and expanded research opportunities will provide unprecedented opportunities to learn about long-term recovery of plant communities following chronic overbrowsing, deer response to changing habitat conditions, hunter attitudes, and the willingness and ability of land managers to invest in site-specific engagement of hunters.

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