

# Is the Deer Population Above Forest Ecological Carrying Capacity in Rose Valley, Pennsylvania, Wildlife Sanctuaries?

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## Abstract

A variety of observations in the roughly 36 acres of wildlife sanctuaries owned and managed by the borough of Rose Valley have long been consistent with ongoing severe forest degradation by the white-tailed deer population. To test that hypothesis, we undertook a rigorous, quantitative approach to isolating and measuring deer impacts separately from all other effects on vegetation. We planted identical arrays of 95 native small trees, shrubs, and herbaceous plants of nine species (“phytometers”) in adjacent cleared plots matched in soils, topography, and sun exposure, one in which deer and no other herbivores were excluded and one accessible to deer. After 17 months of growth and herbivory, we measured survival, flowering/fruiting status, stem count per plant, and height of each plant’s tallest stem. We tallied spontaneously growing (unplanted) vegetation in each plot and compared species diversity (richness and evenness separately) and relative estimated population sizes among native and nonnative invasive species. The results showed extreme differences between the deer-present and deer-excluded plots in survival and performance of planted phytometers and composition of unplanted vegetation. Where deer were present, phytometer survival, rate of flowering, and number and height of stems were far lower, unplanted vegetation species richness and evenness were far lower, and dominance by nonnative invasive species was far higher than where deer were excluded.

Even though participants in a yearly bow hunt since 2011 and a cull performed in 2012 reported removing a total over nine years of 53 antlerless and 10 antlered deer, we conclude that the current deer population is still so high that (1) it is severely degrading the forest ecosystem; (2) opportunity costs of inadequate deer herd control are substantial; and (3) the success of Rose Valley’s forest restoration and stewardship program critically depends on reducing the herd to ecological carrying capacity. The sooner the borough’s land stewards can succeed in reducing and maintaining the deer herd to a size that makes it possible to meet the forest management goals — restoring and sustaining native tree regeneration, native species diversity, and full function of habitat for *all* wildlife in all forest strata (canopy, subcanopy, shrub, and ground layers) — the less difficult and expensive meeting those goals will be. Key to meeting those goals is (1) conducting a crossbow sharpshooter cull as soon as possible; (2) continuing to monitor the ecological impacts of the deer herd; and (3) continually fine-tuning the balance of managed hunting and culling to sustain target levels of tree regeneration and the other metrics of forest ecosystem integrity permanently.

## Introduction

### *The problem*

Observations by users who are trained scientists or well-informed natural history devotees have long supported the conclusion that the white-tailed deer (*Odocoileus virginianus*) population in the wildlife sanctuaries of the borough of Rose Valley, Pennsylvania, is considerably above ecological carrying capacity (*sensu* McShea 2012), despite having been open to bowhunting every year since 2011 and a cull having been conducted in early 2012. Quotes from the scientific literature summarize the problem best:

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Ecological carrying capacity focuses on the interaction between a population of herbivores (plant-eaters, such as white-tailed deer) and the plants that they eat. It is defined as “the maximum density of animals that can be sustained in the absence of harvesting without inducing trends in vegetation” (Krebs 1978). At ecological carrying capacity, the rate of browsing is roughly equal to the rate of food-plant regrowth. The definition also implies that there are no major changes in plant species composition resulting from an increase in the density of an animal population. [Latham et al. 2005]

Deer have expanded their range and increased dramatically in abundance worldwide in recent decades. They inflict major economic losses in forestry, agriculture, and transportation and contribute to the transmission of several animal and human diseases. Their impact on natural ecosystems is also dramatic but less quantified. By foraging selectively, deer affect the growth and survival of many herb, shrub, and tree species, modifying patterns of relative abundance and vegetation dynamics. Cascading effects on other species extend to insects, birds, and other mammals. In forests, sustained overbrowsing reduces plant cover and diversity, alters nutrient and carbon cycling, and redirects succession to shift future overstory composition. Many of these simplified alternative states appear to be stable and difficult to reverse. Given the influence of deer on other organisms and natural processes, ecologists should actively participate in efforts to understand, monitor, and reduce the impact of deer on ecosystems. [Côté et al. 2004]

Sustaining high levels of native species richness is essential to maintaining or restoring ecological services and resilience of forests (Gamfeldt et al. 2013) now and for the coming generations. That resilience is existentially important in the era of intercontinental transmission of new diseases and pests, global climate change, and other novel stresses that threaten ecological collapse.

In the approximately 15 acres of forest currently open to hunting in Rose Valley: (1) there is a total failure of native tree reproduction (seedlings larger than a few inches tall and saplings are absent); (2) the shrub layer is nonexistent in some areas and dominated by a single native species of low browse preference with nonnative invasive species proliferating in others; (3) many shrubs are dwarfed and their twigs severely browsed; and (4) the ground layer is depauperate in native herbaceous species and in most areas is dominated by nonnative invasives. Residents see deer regularly throughout the borough on residential properties, in the wildlife sanctuaries, and on roads, frequently in large groups.

### **Objectives**

The Rose Valley Borough Council has tasked its Environmental Advisory Council (EAC) with managing the borough-owned wildlife sanctuaries to protect and restore wildlife and native vegetation for the enjoyment and education of residents of the borough and surrounding communities and to preserve and enhance quality of life for present and future generations. This is in alignment with the Pennsylvania constitution’s environmental rights amendment and the Pennsylvania Game Commission’s stated mission.

*The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people.* [Section 27, Article 1, Pennsylvania Constitution]

*Pennsylvania Game Commission—Mission: To manage Pennsylvania's wild birds, wild mammals, and their habitats for current and future generations.* [[www.pgc.pa.gov/InformationResources/AboutUs](http://www.pgc.pa.gov/InformationResources/AboutUs)]

**The goal of the borough’s forest management program is to restore and sustain native tree regeneration, native species diversity, and full function of habitat for *all* wildlife, including species that depend on each level of the forest — the canopy, subcanopy, shrub, and ground layers.** To those ends the EAC, in partnership with the Chester-Ridley-Crum Watersheds Association, has applied for and received grants from various sources, including the Pennsylvania Department of Conservation and Natural Resources, and has mustered a heroic amount of volunteer labor over the past 10+ years to fight invasives, plant native trees, shrubs, and herbaceous plants, build temporary deer fences around plantings, and attempt to reduce the deer population to ecological carrying capacity and keep it there. Despite modest success — restoration of 5 to 6 acres of forest in the area most heavily used by hikers, joggers, and other recreationists (presumably curtailing the amount of time deer spend feeding there each day) — **the public**

**forestland in the borough remains highly degraded, and due to failure of native tree regeneration, is not sustainable as forest.** Borough Council and the EAC have fiduciary responsibility to do what is necessary and feasible to carry out the forest management goal, including reducing deer numbers to ecological carrying capacity and maintaining them at that level permanently.

Prior to the start of Rose Valley's deer management program there were two town meetings devoted entirely to the subject and there is ongoing civic dialog among residents and officials at Borough Council meetings and elsewhere. Although a small minority of residents have expressed opposition to lethal means of managing the deer population, a majority have voiced their support for a deer management program and its goals. The main difference of opinion is on how best to carry out reduction and maintenance of deer numbers. Some argue in favor of hiring professionals to perform periodic culls without opening the land to public hunting. However, the Pennsylvania Game Commission's current policy prohibits issuing culling permits to municipalities unless they provide opportunities for recreational hunting beforehand.

#### ***Deer exclusion and planted phytometer approach***

The Rose Valley EAC wanted to test whether monitoring ongoing deer impacts on existing plants, as is prescribed for example in the AVID protocol (Sullivan et al. 2017), may be an inadequate approach for assessing the true deer impacts on ecosystems in the particular case of Rose Valley's hunted wildlife sanctuary land, based on several biologically based premises:

1. Decades of exposure to deer populations in excess of ecological carrying capacity has reduced the shrub- and ground-layer flora to dominance by species that are least preferred by deer, making the current deer population's impact on surviving individuals of the remaining species an inadequate indicator of its true ecological impact given that the desired forest ecosystem consists of the full historical range of locally indigenous forest species.
2. Remaining understory shrubs are so severely browsed already that it is infeasible to assess the degree of ongoing additional browsing.
3. The herbaceous understory is absent in many areas and in other areas consists of species not browsed by deer, mainly Japanese stiltgrass, garlic mustard, other nonnatives, and ferns.

Assessing deer browsing impact where the diversity and abundance of potential indicator species are already severely degraded is a difficult challenge. The only sure way to compensate for the unavailability of appropriate indicators that can be measured is to plant species that are known to have been present in similar habitats in the region. And the only sure way to separate deer effects from all other influences is to plant those species in identical adjacent plots, where deer and no other herbivores are excluded from one and not the other, and compare key performance metrics — survival, growth, and reproductive output. Plants used in such a manner to quantify and compare the ecological effects of experimentally controlled stresses are termed "phytometers." This approach is the gold standard for measuring ecological effects on plants (Dietrich et al. 2013).

## **Study Site and Methods**

### ***Location and site description***

The borough of Rose Valley (see map in Figure 1) is located in the Northern Piedmont along its transition to the Atlantic Coastal Plain, termed the Fall Line. The uplands are part of the Northern Piedmont plateau and are underlain by schist and gneiss of Precambrian age. The valleys are steep-sided with narrow floodplains along Ridley Creek and its tributaries Vernon Run and Minquas Run. Land use is mainly residential, with less than 10% of the area devoted to seven institutional uses\* and several parks; there is no commercial land use. The estimated 2018 human population was 988 (U.S. Census Bureau 2019). The total area of the borough is approximately 450 acres. Population density is 2.2 people per acre.

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\* A private school, historical museum, community swimming pool, repertory theater, social club, church, and cemetery.

The area currently open to hunting (Figure 2) is roughly two-fifths of the approximately 36 acres of borough-owned wildlife sanctuary land on both sides of Ridley Creek. Public use of the wildlife sanctuaries is mainly trail walking year-round and bowhunting seasonally. The Saul Wildlife Sanctuary has a large parking lot and is heavily used by trail walkers, including dog walkers, from throughout Rose Valley and surrounding communities. The Long Point Wildlife Sanctuary and Todmorden Woods are relatively inaccessible and mainly serve their local neighborhoods; they have been open to deer hunting every season since fall 2011. The Saul Wildlife Sanctuary was open to hunting from fall 2011 through winter 2018 but has been closed to hunting for the 2018-2019 and 2019-2020 seasons. During the 2012 cull, which was conducted at night, at least one-third of the deer take was in the Saul Wildlife Sanctuary but no hunters succeeded in taking any deer there during normal hunting hours from 2011 through early 2018. That failure is attributed to other visitors ignoring the posted closure to non-hunter access in early morning and late afternoon hours and interfering with hunters, which also posed safety concerns. The borough government operates on a shoestring and has no enforcement capability to limit park use.

Nearly all of the land in the Rose Valley wildlife sanctuaries is covered by mature forest, with tuliptree (*Liriodendron tulipifera*) up to 5 feet 10 inches dbh (diameter at “breast height,” 54 inches from ground level), northern red oak (*Quercus rubra*) and white oak (*Quercus alba*) regularly reaching 4 to 4½ feet dbh, black oak (*Quercus velutina*) and American beech (*Fagus grandifolia*) up to 3½ feet dbh, black walnut (*Juglans nigra*) up to 3 feet dbh, and blackgum (*Nyssa sylvatica*) up to 2½ feet dbh. There are three forest communities (classification is from Zimmerman et al. 2012). In order of total land cover within the combined Long Point Wildlife Sanctuary and Todmorden Woods (Figure 2), they are as follows:

1. **Tuliptree – Beech – Maple Forest** occupies mid- and lower slopes underlain by schist or gneiss and a narrow zone of alluvium on the adjoining upper floodplain. Soils are mainly Manor loams (coarse-loamy, micaceous, mesic Typic Dystrudepts) with a few massive boulder outcrops on steep slopes where the bedrock is gneiss. It is dominated by tuliptree, American beech, red maple (*Acer rubrum*), black walnut, and northern red oak, with scattered blackgum, bitternut hickory (*Carya cordiformis*), white oak, and sugar maple (*Acer saccharum*). The shrub layer consists almost entirely of one native shrub species and several nonnative invasive shrub and woody vine species. The most abundant shrub is the native spicebush (*Lindera benzoin*); also present but sparsely or patchily distributed are Allegheny blackberry (*Rubus allegheniensis*), American witch-hazel (*Hamamelis virginiana*), and American bladdernut (*Staphylea trifolia*). Native woody vines are Virginia creeper (*Parthenocissus quinquefolia*), poison-ivy (*Toxicodendron radicans*), and summer grape (*Vitis aestivalis*). Also present and apparently increasing are the nonnative invasives Amur honeysuckle (*Lonicera maackii*), multiflora rose (*Rosa multiflora*), burningbush (*Euonymus alatus*), border privet (*Ligustrum obtusifolium*), sapphire-berry (*Symplocos paniculata*), linden viburnum (*Viburnum dilatatum*), Siebold viburnum (*V. sieboldii*), Japanese angelica-tree (*Aralia elata*), Oriental photinia (*Pourthiaea villosa*), Siberian crabapple (*Malus baccata*), showy crabapple (*M. floribunda*), jetbead (*Rhodotypos scandens*), Japanese barberry (*Berberis thunbergii*), wineberry (*Rubus phoenicolasius*), Japanese zelkova (*Zelkova serrata*), English ivy (*Hedera helix*), Oriental bittersweet (*Celastrus orbiculatus*), Japanese honeysuckle (*Lonicera japonica*), and Japanese pachysandra (*Pachysandra terminalis*). Common herbaceous species include the nonnative invasives garlic mustard (*Alliaria petiolata*), Japanese stiltgrass (*Microstegium vimineum*), and gill-over-the-ground (*Glechoma hederacea*) and the natives white snakeroot (*Ageratina altissima*), Christmas fern (*Polystichum acrostichoides*), spinulose wood fern (*Dryopteris carthusiana*), honewort (*Cryptotaenia canadensis*), and jumpseed (*Persicaria virginiana*).
2. **Green Ash – Mixed Hardwood Floodplain Forest** occurs in a 10- to 25-foot-wide riparian zone along Ridley Creek on soils derived from alluvium, partly consisting of thick legacy sediments from 18th- and 19th-century mill ponds. Soils are mainly Wehadkee silt loams (fine-loamy, mixed, active, nonacid, thermic Fluvaquentic Endoaquepts). It is dominated by green ash (*Fraxinus pennsylvanica*), sycamore (*Platanus occidentalis*), silver maple (*Acer saccharinum*), black walnut, boxelder (*Acer negundo*), and tuliptree, with scattered bitternut hickory and American basswood (*Tilia americana*). Shrubs are the natives spicebush and pawpaw (*Asimina triloba*) along with the same nonnative shrubs and woody vines as are listed above under Tuliptree – Beech – Maple Forest. The herbaceous layer is dominated by nonnative invasives including Japanese knotweed (*Reynoutria japonica*), Japanese stiltgrass, lesser celandine (*Ficaria verna*), mile-a-minute (*Persicaria perfoliata*), bristly lady’s-thumb (*P. longisetata*), Japanese hops (*Humulus japonicus*), goutweed (*Aegopodium podagraria*), and gill-over-the-ground. Common native herbaceous



species include white snakeroot, stingless nettle (*Boehmeria cylindrica*), wood nettle (*Laportea canadensis*), and the spring ephemerals spring-beauty (*Claytonia virginica*) and yellow trout lily (*Erythronium americanum*).

3. A distinctly Northern Piedmont variant of [Dry Oak – Heath Forest](#) covers the upper slopes and top of the narrow ridge in the Long Point Wildlife Sanctuary overlying gneiss. Soils are mainly Manor channery loams (coarse-loamy, micaceous, mesic Typic Dystrudepts) with a few massive boulder outcrops along the ridgetop. It is dominated by white oak, scarlet oak (*Q. coccinea*), northern red oak, black oak, blackgum, and American beech. **There is a small, apparently aboriginal, population of fully grown southern red oak (*Quercus falcata*), a Pennsylvania Endangered species restricted to the Piedmont and Coastal Plain.** The shrub layer is sparse and consists of the natives mountain-laurel (*Kalmia latifolia*) and maple-leaf viburnum (*Viburnum acerifolium*) and the nonnative invasive burningbush. The extremely sparse ground layer also includes isolated plants of poverty oatgrass (*Danthonia spicata*), partridgeberry (*Mitchella repens*), striped wintergreen (*Chimaphila maculata*), and white wood aster (*Eurybia divaricata*). There is no regeneration (seedlings or saplings) of any tree species or mountain-laurel. Adult mountain-laurels have a sharp browse line 4 to 5 feet above the ground and the few maple-leaf viburnum and burningbush stems are dwarfed and have severely browsed tips.

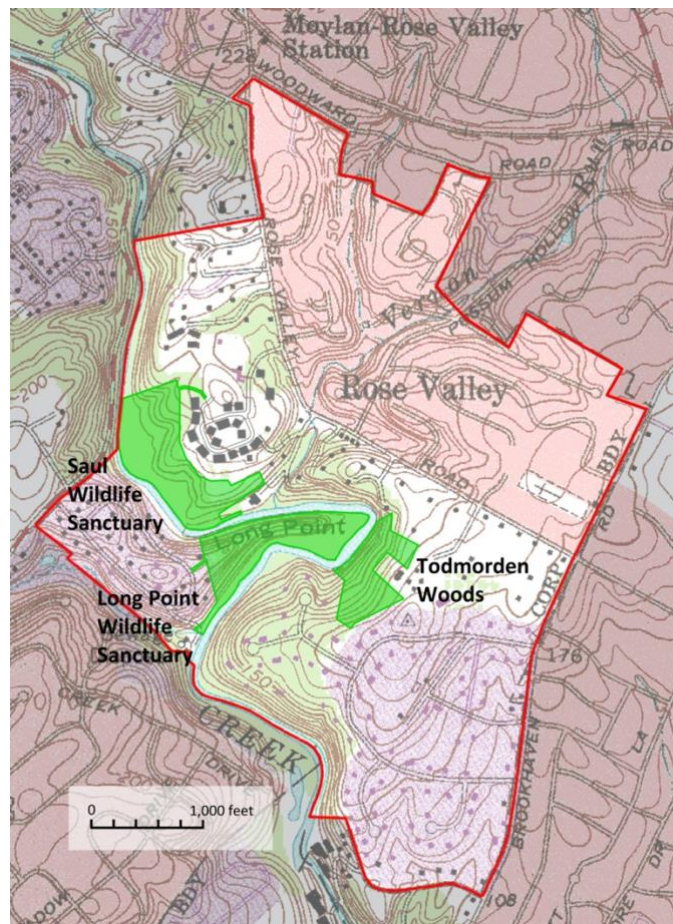


Figure 1. **Location map of Rose Valley wildlife sanctuaries** (in green). The borough of Rose Valley is the area within the red line, approximately 450 acres.



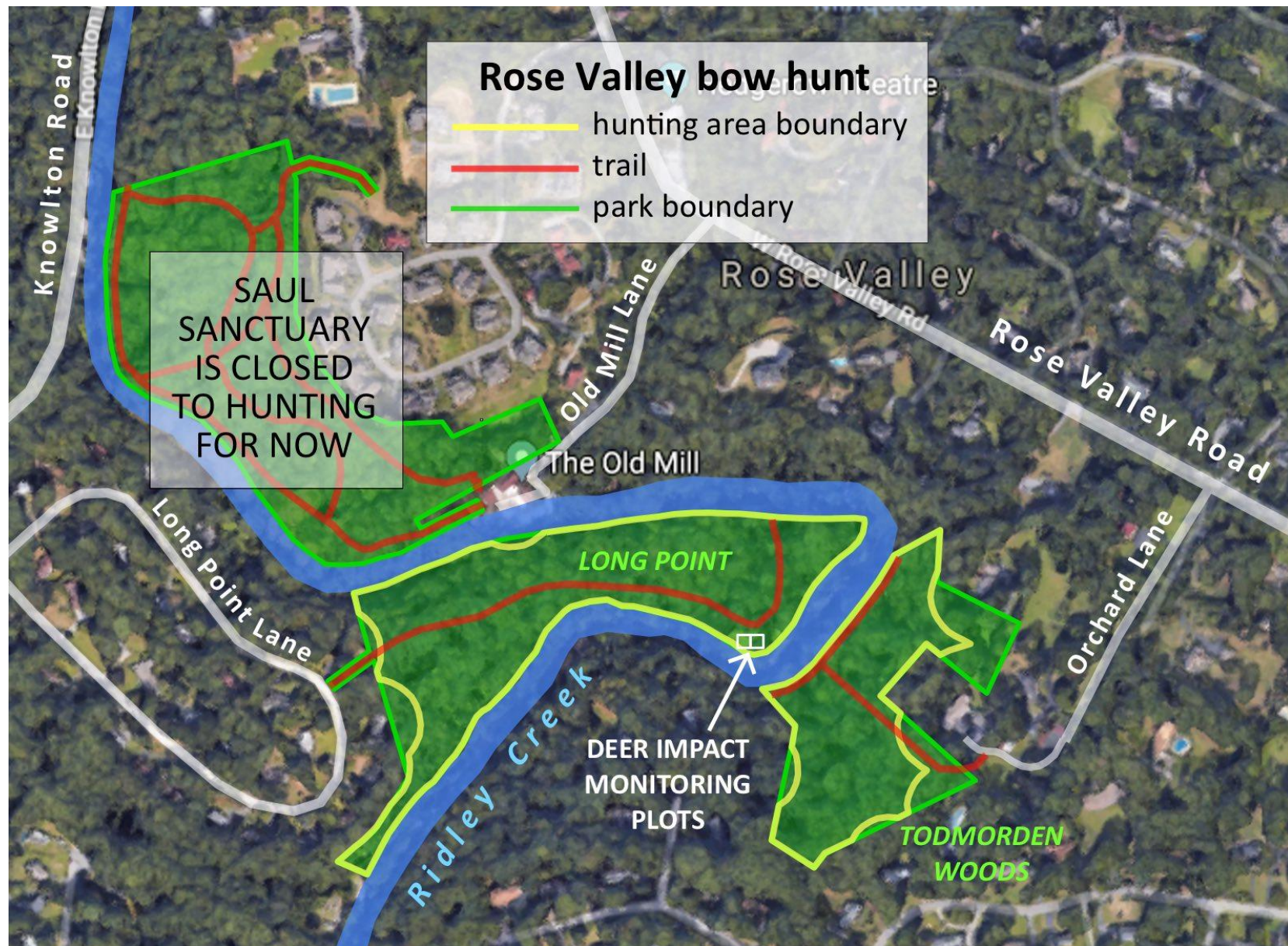


Figure 2. Location map of bowhunting area and deer impact monitoring plots in Rose Valley, Pennsylvania.





Figure 3. **Deer impact monitoring plots.** Deer enclosure is at left. Post at far right marks outside corner of plot with deer present. Ridgetop is in background, Ridley Creek in foreground.

#### ***Site selection and preparation for deer impact monitoring***

Two adjacent 30-foot  $\times$  30-foot plots were established between the foot of the steep slope at the edge of the Dry Oak – Heath Forest and the Green Ash – Mixed Hardwood Floodplain Forest near the center of the combined Long Point Wildlife Sanctuary and Todmorden Woods (Figure 2). The ground is level and high enough above the streambed of Ridley Creek to avoid inundation in all but the most extreme storm events. One plot was fenced with 10-foot-tall woven wire with an aperture size that excludes deer but allows entry by all other herbivores, including eastern cottontail (*Sylvilagus floridanus*) and woodchuck (*Marmota monax*), and the other was left unfenced and marked in the corners opposite the fenced plot by posts (Figure 3). Plots were prepared by felling trees to thin the canopy so both plots have approximately the same sun exposure and clearing (uprooting or cutting) all ground vegetation. Clearing was done on 7 April 2018.

#### ***Phytometer planting***

On the same day as clearing, four woody and five herbaceous native species appropriate to site conditions were planted in each plot (Table 1) in identical arrays, at the centers of 95 of the 100 cells in a 10  $\times$  10 grid of 3-foot  $\times$  3-foot squares. Shrubs and small trees were 2- to 3-foot-tall bare-root whips purchased from Octoraro Native Plant Nursery, Lancaster County, PA, and herbaceous plants were pot-grown plugs purchased from North Creek Nurseries, Chester County, PA. Plants were watered immediately after planting.

#### ***Data collection***

Data were gathered on 27 August 2019, roughly 17 months after clearing and planting. For each individual of the planted species, its position was recorded as x- and y-coordinates in the 10  $\times$  10 planting grid, its stems were counted, the length of its tallest stem was measured to the nearest 5 cm, and whether the plant was flowering or fruiting was noted. The same data were also collected on three spontaneously growing (unplanted) conspicuous species in the plots: green ash seedlings  $\geq$  50 cm tall and all individuals

of black elderberry (*Sambucus canadensis*) and summer phlox (*Phlox paniculata*). A tally was made of all species growing spontaneously within each plot. Since it was not practical to count individuals, each species' population in each plot was estimated as belonging to one of four categorical ranges: > 500 individuals (dominant), 51-500 (common), 11-50 (occasional), and 1-10 (rare).

Table 1. **Species mix of the 95 native small trees, shrubs, and herbaceous plants planted in each plot.** Woody plants are in brown type, herbaceous plants in green type.

common name	species	planted in each plot
Canadian serviceberry	<i>Amelanchier canadensis</i>	5
black chokeberry	<i>Aronia melanocarpa</i>	5
American hornbeam	<i>Carpinus caroliniana</i>	5
silky dogwood	<i>Cornus amomum</i>	5
<b>all planted woody species</b>		<b>20</b>
sweet-scented Joe-Pye-weed	<i>Eutrochium purpureum</i>	15
wild bergamot	<i>Monarda fistulosa</i>	15
green-headed coneflower	<i>Rudbeckia laciniata</i>	15
New York ironweed	<i>Vernonia noveboracensis</i>	15
Culver's-root	<i>Veronicastrum virginicum</i>	15
<b>all planted herbaceous species</b>		<b>75</b>

### Data analysis

Data were summarized graphically and numerically to compare conditions between the two plots. Formal calculation of *P*-values — the probability of finding the observed, or more extreme, differences when the null hypothesis ( $H_0$ ) of our study question is true, namely, the deer population has no demonstrable ecological effect through their browsing — is not possible due to the lack of replication.

## Results

### Phytometers

Survival of phytometers was severely curtailed where deer were present compared with where they were excluded (Figure 4A and Table 2). With exposure to deer browsing less than one-fifth as many woody plants survived and about half as many herbaceous plants. Among herbaceous plants, about one-third as many deer-exposed plants produced any flowers or fruits — 10 versus 29 (Figure 4B). Of the surviving woody plants, the average number of stems per plant where deer browsed was half that of where deer were excluded; surviving herbaceous plants fared somewhat better at five-sixths the average stem number outside as inside the fence (Figure 4C and Table 3). Average height of the tallest stem of woody plants was severely reduced by deer browsing to about one-third that of where deer were excluded; for herbaceous plants the figure was just over two-thirds (Figure 4D and Table 3).

### Spontaneously growing vegetation

Despite lower competition from far fewer and far smaller surviving planted stock, unplanted “volunteer” vegetation where deer were present had less than two-fifths the species richness (Figures 5, 6, and 7 and Table 4), just over two-fifths the species evenness, and far greater numbers and relative proportion of nonnative invasive plants than where deer were excluded (Table 5). The number of nonnative species was higher where deer were excluded (Table 4) but their estimated populations summed to smaller overall numbers and they included several woody species, which were nearly absent from where deer were present (Figure 7 and Appendix 1). The fence itself facilitated at least three of the nonnatives — mile-a-minute, Japanese hops, and porcelainberry (*Ampelopsis brevipedunculata*), which are vine species found there in small numbers and only climbing the fence.



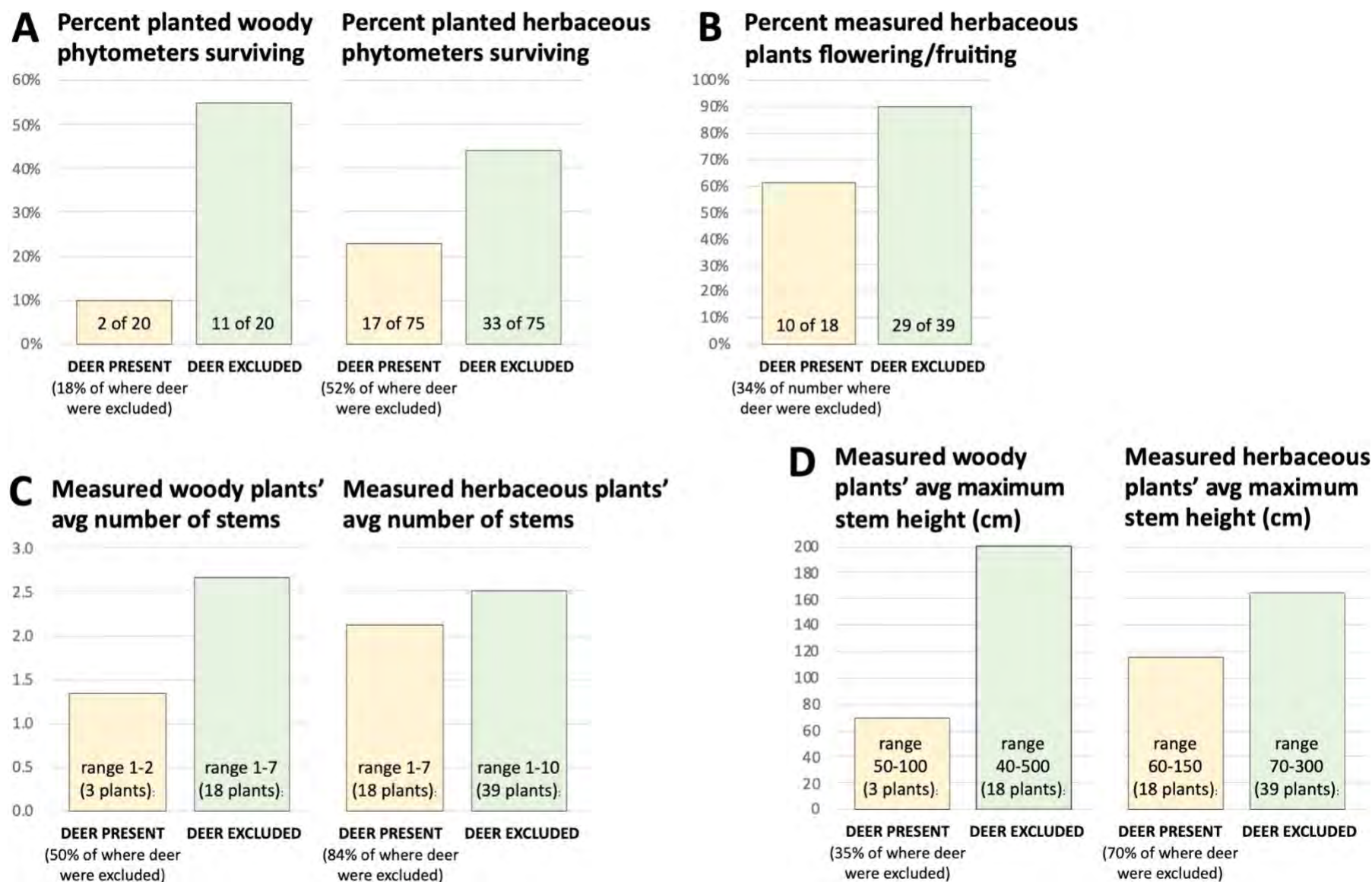


Figure 4. **Survival, growth, and flowering/fruiting of phytometers (planted arrays of nine native species) and three spontaneously growing species.** Averages in C and D were weighted by the number of individuals present of each species. Averages for individual species are in Table 1. Data are summarized over all species in Table 2.

Table 2. Survival and flowering/fruiting of planted phytometers and other measured plants.

	DEER PRESENT		DEER EXCLUDED			DEER PRESENT	DEER EXCLUDED	
PLANTED STOCK common name	plants surviving	percent survival	plants surviving	percent survival	result in unfenced area as % of result in fenced area	weighted % survivors flowering or fruiting	weighted % survivors flowering or fruiting	result in unfenced area as % of result in fenced area
Canadian serviceberry	0	0%	0	0%	—	No shrubs or small trees were mature enough to flower within 17 months after clearing and planting.		
black chokeberry	0	0%	3	60%	0%			
American hornbeam	2	40%	3	60%	67%			
silky dogwood	0	0%	5	100%	0%			
<b>woody plants</b>	<b>2</b>	<b>10%</b>	<b>11</b>	<b>55%</b>	<b>18%</b>			
sweet-scented Joe-Pye-weed	0	0%	7	47%	0%	0	100%	0%
wild bergamot	16	107%	6	40%	267%	63%	100%	63%
green-headed coneflower	0	0%	11	73%	0%	0	100%	0%
New York ironweed	1	7%	6	40%	17%	0%	50%	0%
Culver's-root	0	0%	3	20%	0%	0	67%	0%
<b>herbaceous plants</b>	<b>17</b>	<b>23%</b>	<b>33</b>	<b>44%</b>	<b>52%</b>	<b>59%</b>	<b>88%</b>	<b>67%</b>
MEASURED VOLUNTEER PLANTS common name	plants present		plants present		result in unfenced area as % of result in fenced area	unfenced % flowering or fruiting	fenced % flowering or fruiting	result in unfenced area as % of result in fenced area
summer phlox	1		6		17%	100%	100%	100%
ALL MEASURED PLANTS						unfenced weighted % flowering or fruiting	fenced weighted % flowering or fruiting	result in unfenced area as % of result in fenced area
<b>herbaceous plants</b>						<b>61%</b>	<b>90%</b>	<b>68%</b>

Table 3. Number of stems and height of tallest stem of planted phytometers and other measured plants.

	DEER PRESENT		DEER EXCLUDED			DEER PRESENT		DEER EXCLUDED		
PLANTED STOCK common name	weighted avg number of stems per plant	SD*	weighted avg number of stems per plant	SD*	result in unfenced area as % of result in fenced area	weighted avg height of tallest stem (cm)	SD*	weighted avg height of tallest stem (cm)	SD*	result in unfenced area as % of result in fenced area
Canadian serviceberry	—	—	—	—	—	—	—	—	—	—
black chokeberry	0	—	1.7	0.6	0%	0	—	117	67	0%
American hornbeam	1.0	0.0	1.0	0.6	100%	55	7	115	60	48%
silky dogwood	0	—	2.4	0.6	0%	0	—	205	40	0%
<b>woody plants</b>	<b>1.0</b>		<b>1.8</b>		<b>55%</b>	<b>55</b>		<b>156</b>		<b>35%</b>
sweet-scented Joe-Pye-weed	0	—	2.1	2.3	0%	0	—	122	33	0%
wild bergamot	2.3	1.9	2.0	2.3	113%	122	14	148	43	82%
green-headed coneflower	0	—	4.7	2.3	0%	0	—	257	48	0%
New York ironweed	1.0	1.0	1.2	1.2	86%	60	4	121	31	50%
Culver's-root	0	—	2.0	1.0	0%	0	—	123	20	0%
<b>herbaceous plants</b>	<b>2.2</b>		<b>2.8</b>		<b>78%</b>	<b>118</b>		<b>172</b>		<b>69%</b>
MEASURED VOLUNTEER PLANTS common name	avg number of stems per plant	SD*	avg number of stems per plant	SD*	result in unfenced area as % of result in fenced area	weighted avg height of tallest stem (cm)	SD*	weighted avg height of tallest stem (cm)	SD*	result in unfenced area as % of result in fenced area
green ash ≥ 50 cm tall (N = 1)	0	—	1	2.3	0%	—	—	90	114	—
black elderberry (N = 7)	2.0	2.0	4.5	2.3	44%	100	25	303	104	33%
summer phlox (N = 7)	1.0	1.0	1.0	1.2	100%	75	7	124	115	60%
ALL MEASURED PLANTS	weighted avg number of stems per plant		weighted avg number of stems per plant		result in unfenced area as % of result in fenced area	weighted avg height of tallest stem (cm)		weighted avg height of tallest stem (cm)		result in unfenced area as % of result in fenced area
<b>all woody plants (N = 48)</b>	<b>1.3</b>		<b>2.7</b>		<b>50%</b>	<b>70</b>		<b>202</b>		<b>35%</b>
<b>all herbaceous plants (N = 157)</b>	<b>2.1</b>		<b>2.5</b>		<b>84%</b>	<b>116</b>		<b>164</b>		<b>70%</b>

\*SD = standard deviation; should be interpreted with caution as data are not necessarily normally distributed.





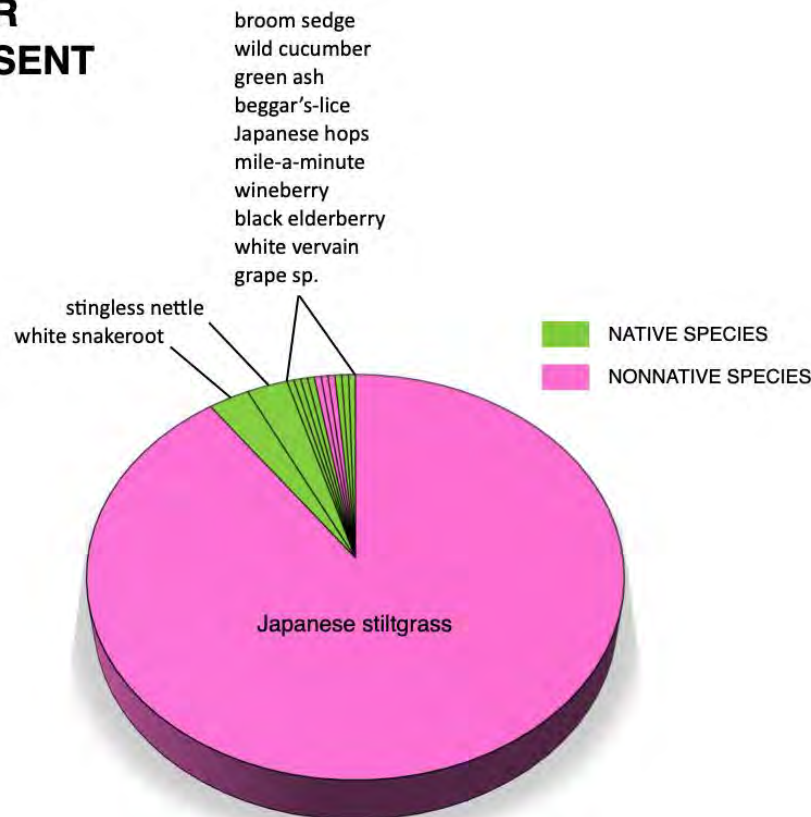
Figure 5. **Wide-angle panorama of plot with deer present.** Photo taken on the day of data collection, 27 August 2019, from center of southwest border along adjoining plot's fence, looking northeast. Red line marks approximate location of 30-foot  $\times$  30-foot plot perimeter at ground level.



Figure 6. **Wide-angle panorama of plot with deer excluded.** Photo taken on the day of data collection, 27 August 2019, from center of southwest border, looking northeast.

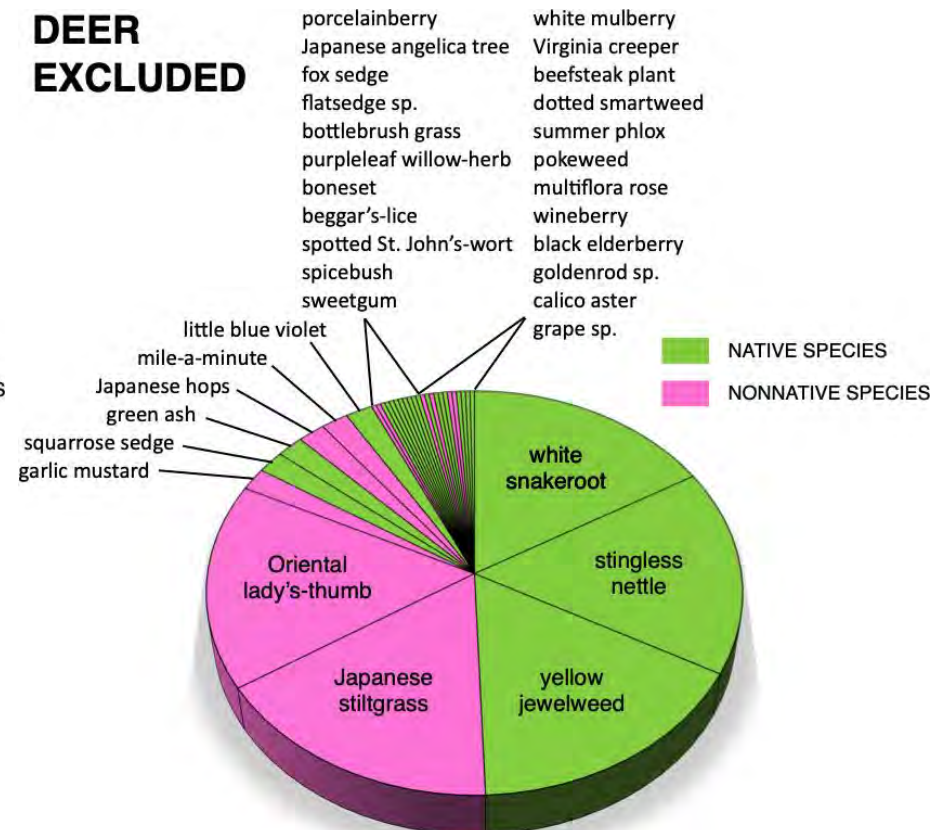


## DEER PRESENT



Total species richness  $S = 13$  (38% of where deer were excluded)  
 Native species richness  $S_N = 9$  (39% of where deer were excluded)  
 Species evenness  $E_{1/D} = 0.095$  (44% of where deer were excluded)

## DEER EXCLUDED



Total species richness  $S = 34$   
 Native species richness  $S_N = 23$   
 Species evenness  $E_{1/D} = 0.214$

Figure 7. **Plant species richness and evenness (the two components of species diversity) and relative population sizes of spontaneously growing plant species.** Pie chart sections represent the proportion of each species' estimated population of the total population of all species present. Planted phytometers (Tables 1, 2, and 3 and Figure 4) were omitted from this analysis. Species richness  $S$  is the number of species present. Species evenness  $E_{1/D}$  (the inverse of dominance) is a variation of Simpson's index that is independent of richness:  $E_{1/D} = 100 \times (1/\sum((n_i(n_i - 1))/(N(N - 1))))/S$ , where  $n_i$  = abundance of the  $i$ th species,  $N$  = total abundance, and  $S$  = number of species in the sample. Data are summarized in Tables 4 and 5. Data for each species within each plot are in Appendix 1.

Table 4. **Species richness of spontaneously growing vascular plant species** (see species list in Appendix 1).

	DEER PRESENT	DEER EXCLUDED	result in unfenced area as % of result in fenced area
<b>total species richness (<i>S</i>)</b>	<b>13</b>	<b>34</b>	<b>38%</b>
woody natives	3	6	50%
herbaceous natives	6	17	35%
<b>total native species</b>	<b>9</b>	<b>23</b>	<b>39%</b>
woody nonnatives	1	5	20%
herbaceous nonnatives	3	6	50%
<b>total nonnative species</b>	<b>4</b>	<b>11</b>	<b>36%</b>

Table 5. **Estimated population sizes and species evenness of spontaneously growing vascular plant species** (see species list and population estimation computation in Appendix 1).

	DEER PRESENT	DEER EXCLUDED	result in unfenced area as % of result in fenced area
<b>estimated total population of all species</b>	<b>1,110</b>	<b>1,670</b>	<b>66%</b>
estimated population of woody natives	15	55	27%
estimated population of herbaceous natives	80	940	9%
<b>estimated population of native species</b>	<b>95</b>	<b>995</b>	<b>10%</b>
estimated population of woody nonnatives	5	20	25%
estimated population of herbaceous nonnatives	1,010	645	157%
<b>estimated population of nonnative species</b>	<b>1,015</b>	<b>665</b>	<b>153%</b>
<i>D</i> (dominance)	0.813	0.137	592%
1/ <i>D</i>	1.230	7.286	17%
<b>evenness independent of richness <math>E_{1/D} = (1/D)/S</math></b>	<b>0.095</b>	<b>0.214</b>	<b>44%</b>





**Figure 8. Dry Oak – Heath Forest stand on ridgetop underlain by gneiss, showing near-nonexistent ground layer and browse line on surviving mountain-laurel.**



**Figure 9. Heavily browsed and dwarfed maple-leaf viburnum in sparse ground layer of ridgetop Dry Oak – Heath Forest.**





Figure 10. **Temporary fencing to protect trees, shrubs, and herbaceous stock planted for forest restoration.** For shrubs and herbaceous plants, fencing would have to be permanent and there would be no possibility of plants spreading outside the fences until the deer herd is reduced to ecological carrying capacity and maintained at that level. Stump at right is of removed invasive Norway maple (*Acer platanoides*).



### ***Vegetation outside plots***

General observations throughout the Long Point Wildlife Sanctuary and Todmorden Woods are a crucial part of the results of this study, although no effort was made to quantify species diversity or population numbers.

- No seedlings or saplings of any forest tree species are present except for a small number of widely scattered individuals 10 cm to 40 cm tall, mainly on the floodplain and almost entirely of green ash.
- The population of the Pennsylvania Endangered southern red oak includes no seedlings, saplings, or subcanopy individuals.
- Native shrub cover overall is sparse. Scattered spicebush and witch-hazel are all full-grown; no seedlings have been found. The small mountain-laurel population, confined to the oak-dominated ridgetop, has a well-defined browse line and there are no seedlings (Figure 8). The small maple-leaf viburnum population, also confined to the ridgetop, consists of widely scattered dwarfed plants less than 50 cm tall with heavily browsed branch tips (Figure 9).
- Nonnative invasive shrub cover is dense in small patches, mainly of burningbush and jetbead. Low-statured burningbush plants are severely browsed.
- Plantings to restore native riparian vegetation to a roughly 2½-acre area at Long Point formerly in 100% Japanese knotweed cover, now nearly eradicated, have to be protected with temporary fencing (Figure 10). In a few cases where fencing has been breached, planted stock has been browsed.

Part of the Saul Wildlife Sanctuary that is heavily used by hikers and dog-walkers and a target of much volunteer and contractor restoration work over the past 10 years under the EAC's direction, including invasives removal, natives planting, and streambank stabilization, has been showing signs of forest recovery (see Discussion).

### **Discussion**

Due to the lack of replication in the deer impact monitoring program, biological (as contrasted with statistical) significance must be evaluated based on the preponderance of evidence, both quantitatively from the deer impact monitoring plots and qualitatively from an informed assessment of the condition of the broader ecosystem. The credibility of the deer impact monitoring results hinges on:

1. whether the two plots differ from each other only in the presence or absence of deer (**precision of experimental control**);
2. the sizes of the differences relative to what is considered likely to be biologically significant, in terms of the goals of forest ecosystem restoration and maintenance (**magnitude of difference**); and
3. to what degree vegetation on the plot with deer present resembles the vegetation in the area surrounding the plots (**generality of results**).

#### ***Precision of experimental control***

The 30-foot × 60-foot plot location was carefully selected to be uniform in soils, topography, and the species composition of existing vegetation. Trees were cut to make sure both sides are equally exposed to sunlight. The half to be fenced was randomly picked. Both sides have been treated identically ever since fence installation. The woven wire mesh used to build the fence was chosen to admit all herbivores except deer, including eastern cottontail and woodchuck.

#### ***Magnitude of difference***

The differences between the deer-present and deer-excluded areas in survival and performance of planted phytometers and spontaneously growing vegetation are extreme. Their biological significance is beyond question.

#### ***Generality of results***

Differences between the vegetation in the unfenced plot at the time of data collection and the spontaneously growing vegetation surrounding the plots are minimal.



The probability of finding these results when the null hypothesis ( $H_0$ ) of our study question is true — namely, that the deer population has no demonstrable ecological effect through their browsing — is not formally calculable as a  $P$ -value because of the lack of replication. However, by far the most parsimonious interpretation of the results is that it is extremely low. The entire area and the plot where deer were present are similarly severely degraded, while the plot where deer were excluded showed strong signs of recovery of key metrics of forest integrity in a single growing season.

In contrast to the extreme and ongoing forest degradation in the Long Point Wildlife Sanctuary and Todmorden Woods, gradually increasing signs of recovery have been observed in the last 10 years in the most heavily visited part of the nearby Saul Wildlife Sanctuary, including survival of native tree seedlings to large sapling size (which was near zero at the start of the forest restoration program in the late 2000s) and proliferation of native forest wildflowers. Improvement is due in part to volunteer efforts to remove invasives and augment native populations and species diversity by planting, with planting stock purchases funded by DCNR's Growing Greener program and other sources. However, the main cause is likely the popularity, which is apparently rising, of the Saul Wildlife Sanctuary among dog-walkers and hikers, mainly in the 5 to 6 acres (roughly one-third of the sanctuary's total area) closest to the parking area, where visitation is heaviest. Such use can foster a "landscape of fear" among prey animals (Gallagher et al. 2017; Gaynor et al. 2019), curtailing the time they can spend feeding and even reducing reproduction rate. Deer are seen there regularly, usually one or two at a time, flushed from cover or on the run. Deer sightings on residential properties throughout the community and in the other two wildlife sanctuaries are usually of animals feeding or moving at a slower pace, often in large groups.

#### ***Failure of recreational hunting to maintain deer at ecological carrying capacity***

Despite bowhunting by a yearly average of 27 hunters for 7 to 9 weeks each year for 9 years, who have reported taking 38 antlerless and 8 antlered deer in total, and a cull in 2012, which removed another 15 antlerless and 2 antlered deer (Table 6), the ecological impacts of the deer herd in the Long Point Wildlife Sanctuary and Todmorden Woods are so severe as to be incompatible with Rose Valley borough's forest management goals.

**Table 6. Numbers of bowhunters and deer taken in the annual hunt and deer taken in the only cull to date.**

Hunters fielded is the number of licensed hunters who attended mandatory hunter orientation sessions and were issued permits by the borough to hunt deer in the Rose Valley wildlife sanctuaries.

season	hunters fielded	take
2011-2012	23	4 does, 1 buck
2012 post-season cull		15 does, 2 bucks
2012-2013	29	5 does
2013-2014	32	2 does
2014-2015	43	3 does
2015-2016	28	4 does, 1 buck
2016-2017	25	7 does
2017-2018	22	6 does, 3 bucks
2018-2019	26	4 does
2019-2020	16	5 does, 1 buck (as of 22 November)

### ***Opportunity costs of inadequate deer herd control***

Opportunity costs to the Rose Valley community of failing to reduce the deer herd to ecological carrying capacity and maintain it there include the obvious: reduced safety (deer-car collisions, Lyme disease epidemic), property damage (mainly to gardens and landscape plantings), and the expense of preventive measures (fencing, etc.). Just as crucially, and probably more so in the long term, the effects of prolonged overbrowsing and inadequate deer herd control include a steady shift in public perception and loss of collective memory of what is normal and acceptable in the natural environment. A recent review summarizes the trend and its insidious and potentially drastic consequences:

With ongoing environmental degradation at local, regional, and global scales, people's accepted thresholds for environmental conditions are continually being lowered. In the absence of past information or experience with historical conditions, members of each new generation accept the situation in which they were raised as being normal. This psychological and sociological phenomenon is termed **shifting baseline syndrome**, which is increasingly recognized as one of the fundamental obstacles to addressing a wide range of today's global environmental issues. ... [T]here are several self-reinforcing feedback loops that allow the consequences of shifting baseline syndrome to further accelerate shifting baseline syndrome through progressive environmental degradation. Such negative implications highlight the urgent need to dedicate considerable effort to preventing and ultimately reversing shifting baseline syndrome. [Soga and Gaston 2018; emphasis added]

Adverse effects on native forest plant and songbird abundance and diversity caused by deer populations above ecological carrying capacity are well demonstrated (e.g., Chollet et al. 2015; Pendergast et al. 2016), most notably in the U.S. Mid-Atlantic and Great Lakes states. Overbrowsing has been shown to halt tree reproduction, exacerbate nonnative species invasions, increase populations of human disease vectors white-footed mice (*Peromyscus leucopus*) and ticks, and where sustained, simplify and homogenize forest species composition and alter successional trajectories (Côté et al. 2004; Latham et al. 2005; McShea 2012; Shelton et al. 2014). Once established, the novel, depauperate forest communities that result tend to be stable and highly resistant to reversal to a less-degraded state (Côté et al. 2004; Pendergast et al. 2016).

The altered and impoverished forest found today in much of the eastern U.S. is seen by all but the oldest generations as normal. A thoughtful reading of the synthesis by Soga and Gaston (2018) leads to the conclusion that **providing a readily accessible model at the local community scale of less-degraded forest and responsible land management, with well-thought-out interpretation and educational outreach, is a potentially effective way of combating an inexorable slide into acceptance of ever-greater degradation of our natural heritage.**

### **Conclusions**

The current deer population is severely degrading the forest ecosystem of the Long Point Wildlife Sanctuary and Todmorden Woods. The success of Rose Valley's forest restoration and stewardship program critically depends on reducing the herd to ecological carrying capacity. The borough provides ample recreational hunting opportunity, but hunting alone is demonstrably inadequate to maintain deer at ecological carrying capacity without periodic culling.

The stakes are high, and time is short. The sooner Rose Valley's land stewards can succeed in reducing and maintaining the deer herd to ecological carrying capacity, the less difficult and expensive it will be to restore Rose Valley's publicly protected forestlands to their former ability to deliver ecosystem services to their full potential. A crucial next step is to resume, as soon as possible, periodic application of the surest and most efficient tool for regulating a deer population — sharpshooter culling (which in suburban communities like Rose Valley where there is little or no land outside the firearms safety zone, has to be by crossbow). Longer-term key actions include continuing to monitor the ecological impacts of the deer herd and continually fine-tuning the balance of managed hunting and culling to sustain target levels of tree regeneration and the other metrics of forest ecosystem integrity permanently.

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**Appendix 1. Species richness and estimated population sizes of spontaneously growing plant species in deer-impact-monitoring plots at the Long Point Wildlife Sanctuary, Rose Valley, Pennsylvania.**

abundance category code	estimated-abundance category	value used to estimate populations
4	dominant: > 500	1,000
3	common: 51-500	275
2	occasional: 11-50	30
1	rare: 1-10	5

common name	taxon	native/ nonnative	growth form	DEER PRESENT		DEER EXCLUDED	
				abundance category	estimated population	abundance category	estimated population
white snakeroot	<i>Ageratina altissima</i>	native	perennial	2	30	3	275
garlic mustard	<i>Alliaria petiolata</i>	nonnative	biennial			2	30
porcelainberry	<i>Ampelopsis brevipedunculata</i>	nonnative	woody vine			1	5
Japanese angelica tree	<i>Aralia elata</i>	nonnative	shrub/small tree			1	5
stingless nettle	<i>Boehmeria cylindrica</i>	native	perennial	2	30	3	275
broom sedge (?)	<i>Carex scoparia</i>	native	perennial	1	5		
fox sedge (?)	<i>Carex vulpinoidea</i>	native	perennial			1	5
squarrose sedge (?)	<i>Carex squarrosa</i>	native	perennial			2	30
a flatsedge	<i>Cyperus</i> sp.	native?	herbaceous			1	5
wild cucumber	<i>Echinocystis lobata</i>	native	annual	1	5		
bottlebrush grass	<i>Elymus hystrix</i>	native	perennial			1	5
purpleleaf willow-herb	<i>Epilobium coloratum</i>	native	perennial			1	5
boneset	<i>Eupatorium perfoliatum</i>	native	perennial			1	5
green ash	<i>Fraxinus pennsylvanica</i>	native	tree seedling	1	5	2	30
beggar's-lice	<i>Hackelia virginiana</i>	native	biennial	1	5	1	5
Japanese hops	<i>Humulus japonicus</i>	nonnative	annual	1	5	2	30
spotted St. John's-wort	<i>Hypericum punctatum</i>	native	perennial			1	5
yellow jewelweed	<i>Impatiens pallida</i>	native	annual			3	275
spicebush	<i>Lindera benzoin</i>	native	shrub			1	5
sweetgum	<i>Liquidambar styraciflua</i>	native	tree seedling			1	5
Japanese stiltgrass	<i>Microstegium vimineum</i>	nonnative	annual	4	1000	3	275
white mulberry	<i>Morus alba</i>	nonnative	tree seedling			1	5
Virginia creeper	<i>Parthenocissus quinquefolia</i>	native	woody vine			1	5

(Table continued on next page.)

				DEER PRESENT		DEER EXCLUDED	
common name	taxon	native/ nonnative	growth form	abundance category	estimated population	abundance category	estimated population
beefsteak plant	<i>Perilla frutescens</i>	nonnative	annual			1	5
Oriental lady's-thumb	<i>Persicaria longiseta</i>	nonnative	annual			3	275
mile-a-minute	<i>Persicaria perfoliata</i>	nonnative	annual	1	5	2	30
dotted smartweed	<i>Persicaria punctata</i>	native	perennial			1	5
summer phlox	<i>Phlox paniculata</i>	native	perennial			1	5
pokeweed	<i>Phytolacca americana</i>	native	perennial			1	5
multiflora rose	<i>Rosa multiflora</i>	nonnative	shrub			1	5
wineberry	<i>Rubus phoenicolasius</i>	nonnative	shrub	1	5	1	5
black elderberry	<i>Sambucus canadensis</i>	native	shrub	1	5	1	5
a goldenrod	<i>Solidago</i> sp.	native	perennial			1	5
calico aster	<i>Symphyotrichum lateriflorum</i>	native	perennial			1	5
white vervain	<i>Verbena urticifolia</i>	native	perennial	1	5		
little blue violet	<i>Viola sororia</i>	native	perennial			2	30
a grape	<i>Vitis</i> sp.	native	woody vine	1	5	1	5