DEVELOPING AND TESTING A RAPID ASSESSMENT PROTOCOL FOR MONITORING VEGETATION CHANGES ON STATE FOREST LANDS

Final Report

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EXECUTIVE SUMMARY

The objective of this study was to develop a forest vegetation survey protocol that could be completed relatively quickly across large forested areas and to test the protocol on areas of state forests enrolled in the Pennsylvania Game Commission's (PGC) Deer Management Assistance Program (DMAP). The protocol was designed to measure forest vegetation characteristics that would likely respond to changes in deer browsing (i.e., deer density) and to be able to collect these data in a cost-effective manner. Initial data from the survey would provide information to assess whether the protocol provided estimates of forest vegetation characteristics (e.g., stem density of tree seedlings) with reasonable precision to be able to detect changes over time.

Eleven DMAP areas were selected for this study that were located in the Moshannon, Susquehannock, Tioga, Elk, Bald Eagle, Tuscarora, Delaware, Loyalsock, Micheaux, Sproul, and Gallitzin state forests and encompassed 311 square miles. The sampling design was a 2-stage design. First, we delineated square-mile blocks across each study area and 54-100% of blocks were selected to be sampled. Second, within each square-mile block we visited 10 sample sites. Thus, there were two sources of variability that needed to be accounted for in the estimation of variances of parameters: variability among blocks and variability among sample points (within blocks).

At each sample point we collected data on tree basal area and diameter at breast height (dbh) by species (via a prism plot), stem densities of shrubs and saplings by species (>1.5 m tall and <10 cm dbh; 1.5 m × 40 m plot), stem densities of tree seedlings by species (30–150 cm tall; 1.5-m radius plot), whether each tree seedlings had been browsed by deer, counts of Indian cucumber, trillium, Canada mayflower, and Jack-in-the-pulpit (1.5-m radius plot), heights of the tallest individual of each of the four flower species (if present), and percent cover of *Rubus*, grasses, ferns, and forbs (3.5-m radius plot).

During summer 2006 we sampled 234 blocks (square miles) across the 11 DMAP areas using three 2-person teams. Within each DMAP area we sampled 90–100% of the blocks on smaller areas (5–20 square miles) and $\geq$54% of the largest areas ($\leq$116 square miles). Vegetation data were collected at more than 2,000 sample points. We intentionally over-sampled blocks to obtain sufficient data to evaluate the statistical precision of results and improve the efficiency of the sampling design.

The precision of estimates ranged from good to poor depending on the vegetation characteristic being measured. The coefficient of variation (CV = SE/mean×100%) is a measure of precision, in which a CV = 20–25% is considered sufficient for management decisions. We formally evaluated the statistical power of this sampling design to detect changes in tree seedling stem densities and heights of Indian cucumber.

For tree seedlings, the precision of stem density estimates was poor (CV = 43–95%). However, we found that one had a >80% chance ($\alpha = 0.05$) of detecting increases of $\geq$800 stems/acre if current stem densities were <400 stems/acre. On sites with greater seedling

stem densities one is unlikely to be able to detect even large changes in stem density, but sites with >1,000 stems/acre already are likely to have good advanced tree regeneration.

The precision of counts of Indian cucumber (mean = <0.1–5.4 plants/plot), the most abundant and widespread flower in this study, were poor (CV = 60–223%) but the precision of percent of plots occupied by this species were better (plots occupied = 2–43%; CV = 34–224%). Mean heights of the tallest Indian cucumber plant had the best precision (CV = 28–63%); however, mean heights were small (7.0 to 21.3 cm) compared to the reported height for typical specimens of this species (20–90 cm). We estimated that this sampling design could have a ≥80% chance (statistical power) of detecting height increases of 8–30 cm depending on the DMAP area.

The precision of percent of plots adequately stocked with advanced tree regeneration was poor (mean adequately stocked = 10–72%; CV = 26–107%), but most sites had <20% of plots adequately stocked, which explains the large CVs (e.g., Susquehannock SF had a CV = 26% and 72% of plots adequately stocked) and suggests that substantial changes in the amount of advanced regeneration could be detected. Similarly, the precision of counts of Canada mayflower had poor precision (CV = 52–522%), but given that few plants were encountered that were flowering we believe substantial changes in the ratio of flowering to non-flowering plants may be possible to detect and we believe this might be a suitable indicator of forest vegetation conditions.

It is possible that if a paired difference or repeated measures statistical analysis were conducted on data that represent forest conditions at two or more points in time that this sampling design would have greater statistical power to detect differences. Because this study only had data from one point in time, however, we could not evaluate the statistical power of such analyses. We believe that our power analyses were conservative and that the true ability of this sampling design to detect changes in forest vegetation may be equal to, or better, than what is presented in this report.

A consistent pattern among all measurements was that variability among blocks was almost inconsequential compared to the variability among sample points (block:plot variance ratios <<1). This means that sampling plots across each square mile block captured much of the heterogeneity in the landscape (which occurred at a fairly local scale), such that the vegetation characteristics averaged across square-mile blocks was similar among blocks. Thus, our recommendation for more efficient sampling is to reduce the number of blocks visited and to increase the number of sample points within each block. For DMAP areas of <20 square miles, we recommend visiting five blocks (sampling fraction ≥25%). For larger DMAP areas, visit an additional block for every additional 10 square miles of area above 20 square miles (sampling fraction ≥20% for 30 mi^2, ≥16% for 50 mi^2, etc.). Also, we recommend each block contain 20 sample points (instead of 10). These changes to the sampling design greatly reduce the number of blocks that need to be visited but result in equivalent precision of estimates at reduced cost.

Under the proposed sampling design, we believe a trained, 2-person crew could sample about five blocks per week. Thus, on smaller DMAP areas (<20 square miles) two people could sample five blocks in less than eight 10-hour days. To minimize the effects of phenological changes on vegetation measurements, we recommend surveys be conducted during June-August and that when an area is re-sampled that the re-visit be conducted within two weeks of the date it was previously sampled. Surveys could probably be conducted every 3–4 years, but costs, management or research objectives, and logistical issues greatly affect the optimal choice for time intervals between samples and we cannot provide specific guidelines based solely on the results of this study.

We estimate it would cost about $15,000–$20,000 each summer data were collected, which would include a two-person crew for about 800–1,000 hours and 5,000 vehicle miles. This crew could likely sample 50–60 square-mile blocks during a summer. Additional expenses would involve database management and data analysis but possibly could be performed by existing staff if an operational database management system were developed.

We recommend retaining the following data collection in the protocols:

- Tree (>10 cm dbh) basal area and dbh to be able to calculate overstory stocking and assess understory light conditions;
- Stem density, by species, of shrubs and saplings >1.5 m tall and <10 cm dbh to assess advanced tree regeneration and identify sites with problems with interference vegetation;
- Percent cover of *Rubus*, ferns, grasses, and forbs primarily to identify sites with >25% fern cover and potential tree regeneration problems;
- Stem density of tree seedlings (30–150 cm tall), by species, to assess advanced tree regeneration;
- Counts of Indian cucumber and Canada mayflower, and to record the number of flowering Canada mayflower; and
- Height of the tallest Indian cucumber on each plot.

Under the proposed sampling protocols, the following forest vegetation indicators could be monitored:

- Percent of plots adequately stocked with advanced tree regeneration on plots with <25% fern cover, <1,000 stems/acre of interference shrubs and saplings, and <75% overstory stocking;
- Stem density of tree seedlings 30–150 cm tall, which could also account plots with interference vegetation and inadequate overstory conditions;
- Counts of Indian cucumber and Canada mayflower;
- Percent of Canada mayflower plants that are flowering; and
- Height of Indian cucumber.

This study by itself does not provide any direct information on the effects of deer browsing on forest vegetation conditions. Furthermore, we do not know by how much the measures that were chosen for this study will actually respond to changes in deer browsing as influenced by changes in deer density. For example, will percent of flowering Canada mayflower increase by 10% or 50% for a given reduction in deer density?

To further refine a vegetation monitoring program based on the recommendations presented in this report, changes in deer density are required during which repeated vegetation measurements are collected. We believe DCNR lands enrolled in DMAP are large enough for such an endeavor. However, there are some challenges. First, such an undertaking requires a long-term perspective and commitment because vegetation responses may require >10 years, although responses by some species of forest herbs may occur sooner. Second, hunter harvest is the single greatest mortality factor for deer in Pennsylvania, and an accurate accounting of hunter harvest would permit stronger inferences about changes in deer densities. Third, it may be necessary to install deer exclosures on the study area to make sure that reduced deer densities should result in a detectable change in vegetation and to identify what type of changes should be expected to occur.

The vegetation monitoring protocol proposed in this report would be fundamental to any attempt to perform forest restoration in a management-research (i.e., adaptive resource management) context. That is, deer and forest land management decisions would be accompanied by a monitoring program so that outcomes could be assessed in a quantitative, objective manner. As monitoring proceeds new data are collected to evaluate and help refine management decisions as well as improve our understanding of how the ecosystem being managed functions. In this context, deer management, forest vegetation monitoring, and land management decisions are all integrated along with a research component.

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The use of trade names does not imply endorsement by the federal government.

INTRODUCTION

The effect of ungulates on vegetation has been recognized since the early 19th century (Watson 1983). However, systematic studies of the effects of ungulate herbivory did not occur until almost the mid-20th century (Leopold 1933, Leopold et al. 1947). Furthermore, even today most experiments of ungulate herbivory compare deer herbivory to deer exclusion (Côté et al. 2004), and manipulated deer densities are rare (Horsley et al. 2003). Such experiments provide a high degree of control, but may be unrealistic for real-world management (i.e., deer exclosures have no relevance to managed landscapes) or they may have limited inferences to larger landscapes (e.g., may be restricted to a specific forest type).

Côté et al. (2004) noted that research is needed that manipulates deer densities and other factors known to influence forest dynamics and that deer management must move beyond a population-based approach to an approach that considers whole-ecosystem effects (also see McShea et al. 1997). The goal of such research should be to provide forest and wildlife managers with specific recommendations at the proper scales, such as x years of $<y$ deer/km^2 over z km^2 (Hobbs 2003, Côté et al. 2004).

Although research experiments can provide managers with a better understanding of how an ecosystem functions, it is too expensive to be part of any operational management decision-making process. What is lacking for both wildlife and forest managers is a way to monitor vegetation characteristics to help inform population management decisions for deer. What is needed is a vegetation monitoring program that is cost-effective and applied at the same scale of deer and forest management. This study was designed to provide information for developing such a monitoring program on large tracts of forest in Pennsylvania.

The objective of this study was to develop a forest vegetation survey protocol that could be completed relatively quickly across large forested areas and to test the protocol on areas of state forests enrolled in the Pennsylvania Game Commission's (PGC) Deer Management Assistance Program (DMAP). The protocol was designed to measure forest vegetation characteristics that would likely respond to changes in deer browsing (i.e., deer density) and to be able to collect data in a cost-effective manner. Initial data from the survey would provide information to assess whether the protocol could provide estimates of forest vegetation characteristics (e.g., stem density of tree seedlings) with reasonable precision to be able to detect changes over time.

STUDY AREAS

The sampling frame consisted of 11 areas delineated by DCNR personnel and enrolled in the Pennsylvania Game Commission's Deer Management Assistance Program during the 2005-06 hunting seasons (Figure 1). These areas were selected by Merlin Benner (Wildlife Biologist, Pennsylvania Department of Conservation and Natural Resources). The DMAP areas (see Table 1) encompassed approximately 311 square miles.

These areas represented oak-hickory forests in the southern portion of the state (e.g., Micheaux State Forest) to the transitional oak-hickory and northern hardwoods forests in central Pennsylvania (e.g., Moshannon State Forest), to the predominantly northern hardwoods forests of northern Pennsylvania (e.g., Tioga State Forest).

A more detailed description of the boundaries and location of study areas is provided in Appendix B.

Table 1. Deer Management Assistance Program (DMAP) areas on Pennsylvania state forests (SF) and state parks (SP) selected for sampling.

DMAP area	Acres	Km^2	$Miles^2$	Description
18	23,398	90.3	36.6	Moshannon SF and Parker Dam SP
29	15,008	57.9	23.5	Susquehannock SF – Denton Hill
44	77,672	299.9	121.4	Tioga SF
54	4,045	15.6	6.3	Elk SF – Dents Run
55	13,969	53.9	21.8	Bald Eagle SF – Paddy Mountain
99	10,556	40.8	16.5	Tuscarora SF – Fowlers Hollow
266	5,906	22.8	9.2	Delaware SF – Promised Land East of U.S. Route 390
370	13,414	51.8	21.0	Wyoming SF
543	3,502	13.5	5.5	Michaux SF
704	25,499	98.5	39.8	Sproul SF – U.S. Route 144
931	6,250	24.1	9.8	Gallitzin SF
TOTAL	199,219	769.2	311.3	

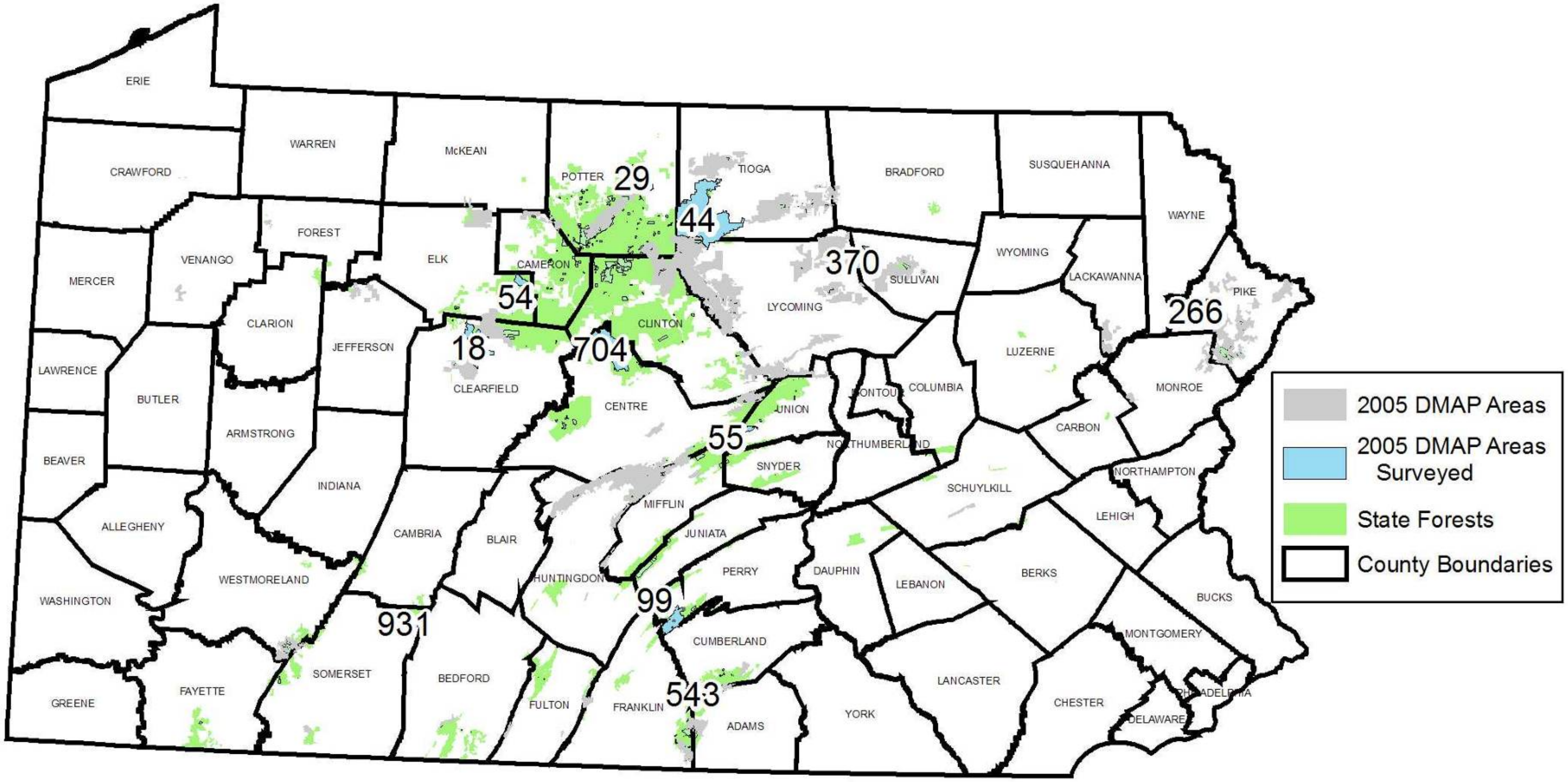

Figure 1. Location of Department of Conservation and Natural Resources lands enrolled in the Pennsylvania Game Commission's Deer Management Assistance Program during the 2005-06 hunting season and the 11 areas selected for this study and surveyed in May-August 2006.

METHODS

Sampling Design

The sampling design was a two-stage design with systematic sampling from a random starting point. At the first stage, a systematic sample from a random starting point of n primary units was selected. From the i^{th} selected primary unit a systematic sample of m_i secondary units was selected, for $I = 1, \ldots, n$ (Figure 2).

Treating the systematic sample with a random starting point as a simple random sample (Thompson 1992), the mean y-value (e.g., y_{ij} might represent basal area measured by a prism tally, counts of seedlings, heights of herbs, etc.) for the i^{th} primary unit in the sample is

$$\hat{\bar{y}}_i = \frac{1}{m_i}\sum_{j=1}^{m_i} y_{ij}$$

Then, because systematic random sampling is used at the first stage, an unbiased estimator of the population mean is

$$\hat{\bar{y}} = \frac{1}{n}\sum_{i=1}^{n} \hat{\bar{y}}_i \quad .$$

The estimated variance of $\hat{\bar{y}}$ is

$$\hat{\text{v}}\text{ar}(\hat{\bar{y}}) = \frac{s_u^2}{n} + \frac{1}{n}\sum_{i=1}^{n}\frac{s_i^2}{m_i}$$

where

$$s_u^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(\hat{\bar{y}}_i - \hat{\bar{y}}\right)^2 \qquad \text{and} \qquad s_i^2 = \frac{1}{m_i - 1}\sum_{j=1}^{m_i}\left(y_{ij} - \hat{\bar{y}}_i\right)^2$$

are the variance terms for the primary and secondary sampling stages, respectively. However, if we sample every primary sampling unit, the finite population correction (fpc $= 1 - \frac{n}{N}$, where n is the actual number of primary sampling units sampled and N is the total number of primary sampling units) causes the first term of the variance formula to go to zero:

$$\hat{\text{v}}\text{ar}(\hat{\bar{y}}) = \left(1 - \frac{n}{N}\right)\frac{s_u^2}{n} + \frac{1}{n}\sum_{i=1}^{n}\frac{s_i^2}{m_i}$$

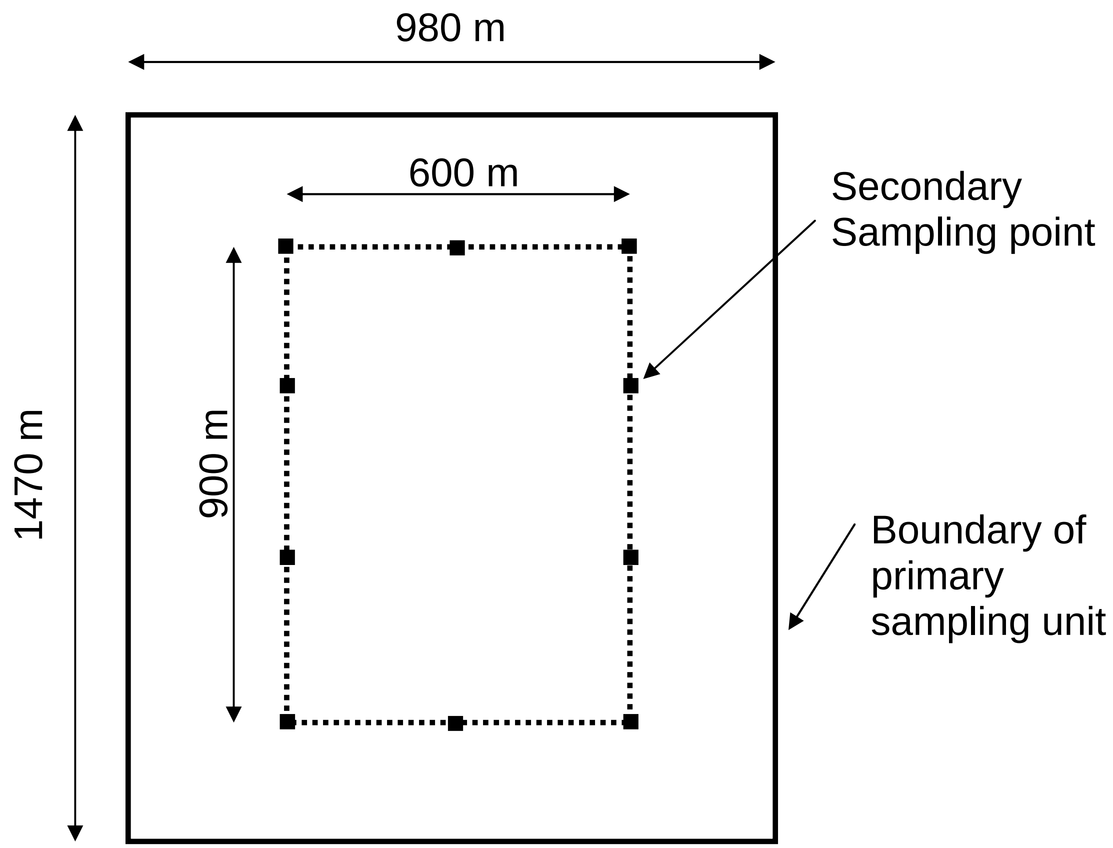

Figure 2. Boundary of primary sampling unit (1 sq. mile = 1470 m × 980 m) and location of 10 secondary sampling units (location of sample plots) within each primary sampling unit.

We ignored the fpc in the formula for the secondary sampling units because the proportion of the area sampled was extremely small and treating the secondary sampling units as if from an infinite sampling frame is acceptable (Cochran 1977).

The above formulas can be used to estimate such parameters as mean basal area, mean stem density, mean height, etc. For presence-absence data the following formulas will be used to estimate the proportion of plots in which the species of interest is present ($y_{ij} = 1$ if present, 0 otherwise; $p_i = a_i/m$ is the proportion of plots with the species present in the subsample from the i^{th} primary sampling unit):

$$s_1^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(p_i - \overline{p}\right) \quad \text{and} \quad s_2^2 = \frac{m}{n(m-1)}\sum_{i=1}^{n} p_i q_i$$

where $\overline{p} = \sum p_i / n$ and

$$\hat{\text{v}}\text{ar}(\overline{p}) = (1-f)\frac{s_1^2}{n} + \frac{s_2^2}{n}.$$

Again, if all primary sampling units are visited then the first term in the variance formula goes to zero.

Sampling Protocols

We sampled ≥54% of primary sampling units on all DMAP areas and on small DMAP areas (<20 sq. miles) we visited all primary sampling units (Table 2). Within each primary sampling unit we visited 10 secondary sampling units (sample points) where data collection occurred.

At each sample point, we collected data on two 1.5-m radius circular plots and one 1.5 m × 40 m rectangular plot (Figure 3). We used Hammerhead tablet PCs (DRS Tactical Systems, West Palm Beach, Florida, USA) with customized database software, which included error detection routines, to record data in the field. Details on the sampling protocols are provided in Appendix A.

The location of each sample point was the center for the first 1.5-m radius plot. At this plot, we recorded the following:

1) Number of trees (>10 cm dbh), by species, using a 20 BAF prism;
2) Diameter of each tree included in the prism sample,
3) Tree seedling (<30 cm tall) species present;
4) Number of seedlings 30–150 cm tall, by species, and whether each seedling was browsed by deer;
5) Number of Canada mayflower, Trillium (*Trillium* spp.), Indian cucumber, and Jack-in-the-pulpit plants; and

6) Height (cm) of the tallest plant for each of the four flower species.

At this same point, we estimated (ocularly) the percent cover of *Rubus*, fern, grass, and forbs on a 3.5-m radius plot.

On the 1.5 m × 40 m rectangular plot we tallied the number of shrubs and tree saplings (>1.5 m tall and <10 cm dbh) by species. Also, we recorded the presence of Viburnum spp. (especially hobblebush [*Viburnum lantanoides*]), elderberry (*Sambucus canadensis*), and greenbriar (*Smilax* spp.).

At the second 1.5-m radius plot we collected the same data (including the percent cover data on a 3.5-m radius plot) except we did not collect tree data using the 20 BAF prism:

1) Tree seedling (<30 cm tall) species present;
2) Number of seedlings 30–150 cm tall, by species, and whether each seedling was browsed by deer;
3) Number of Canada mayflower, Trillium (*Trillium* spp.), Indian cucumber, and Jack-in-the-pulpit plants; and
4) Height (cm) of the tallest plant for each of the four flower species.

Twenty-two blocks were visited early during the sampling period (11 May – 7 June) and revisited later in the summer (20 July – 22 August) to assess how phenological changes in vegetation may have affected plot measurements. In particular, we used these data to measure changes in estimates of percent cover, counts of flower species, presence of flowers, and heights of flowers.

Data Analysis

We used the formulas previously described (see *Sampling Design*) to estimate the mean and variance of basal area, stem density, heights, percent cover, and presence data. Basal area of trees >10 cm dbh was expressed as feet^2/acre and tree bole density was estimated as trees per acre (basal area divided by 0.005454×dbh^2). Stem densities of seedlings, saplings, and shrubs (from 1.5-m radius plots and 1.5 m × 40 m rectangular plots) were calculated on a per acre basis. We did not divide counts of the four flower species by area.

We classified plots with greater than or less than a 75% overstory stocking because plots with <75% overstory stocking have been deemed suitable to expect sufficient light conditions for advanced regeneration to occur (Marquis 1994). We used a stocking chart (Gingrich 1967) to estimate a linear relationship ([basal area] = 85 – 0.0296*[trees/acre]) below which the basal area indicated overstory stocking is <75%.

We identified tree and shrub species as palatable or unpalatable to white-tailed deer based on Latham et al. (2005). Also, we identified species that would interfere with forest tree regeneration (invasive fern species [New York fern *Thelypteris noveboracensis* and hay-scented fern *Dennstaedtia punctilobula*], tree-of-heaven [*Ailanthus altissima*], mountain laurel [*Kalmia latifolia*], striped maple [*Acer pensylvanicum*], black birch [*Betula lenta*], musclewood [*Carpinus carolineana*], American beech (*Fagus grandifolia*; <10 cm dbh), blackgum [*Nyssa sylvatica*], ironwood [*Ostrya virginiana*], *Rhododendron*, autumn olive [*Eleaganus canadensis*], European barberry [*Berberis vulgaris*], multiflora rose [*Rosa multiflora*], and blueberry [*Vaccinium* spp.]).

To assess whether phenological changes affected estimates, we calculated paired-plot differences of measurements (percent cover, presence of four flower species, number of flowers) and used a *t* test with $\alpha = 0.05$ to test if they differed from zero. Also, we plotted the height of flowers as a function of sampling date.

Power Analysis

We estimated the statistical power to detect a change in the mean height of the tallest individual of Indian cucumber and the number of stems/acre of tree seedlings (30-150 cm tall). Indian cucumber was the most widespread and abundant flower and both measures could be expected to change with changes in deer browsing intensity. We performed these analyses for each study area and used the means and variances obtained from this study. We assumed that the means followed a normal distribution, variances were constant, and the Type I error rate was 0.05.

Table 2. Number of primary sampling units (1 sq. mile blocks) within each Deer Management Assistance Program (DMAP) area on state forests (SF) and state parks (SP) and the number and proportion of primary sampling units sampled.

DMAP area	Description	No. primary sampling units	No. primary units sampled	Proportion sampled
18	Moshannon SF and Parker Dam SP	31	29	0.94
29	Susquehannock SF – Denton Hill	24	13	0.54
44	Tioga SF	116	72	0.62
54	Elk SF – Dents Run	7	7	1.00
55	Bald Eagle SF – Paddy Mountain	20	20	1.00
99	Tuscarora SF – Fowlers Hollow	18	18	1.00
266	Delaware SF – Promised Land SP east of U.S. Route 390	10	9	0.90
370	Wyoming SF	19	12	0.63
543	Michaux SF	5	5	1.00
704	Sproul SF – Rte 144	40	39	0.97
931	Gallitzin SF	10	10	1.00

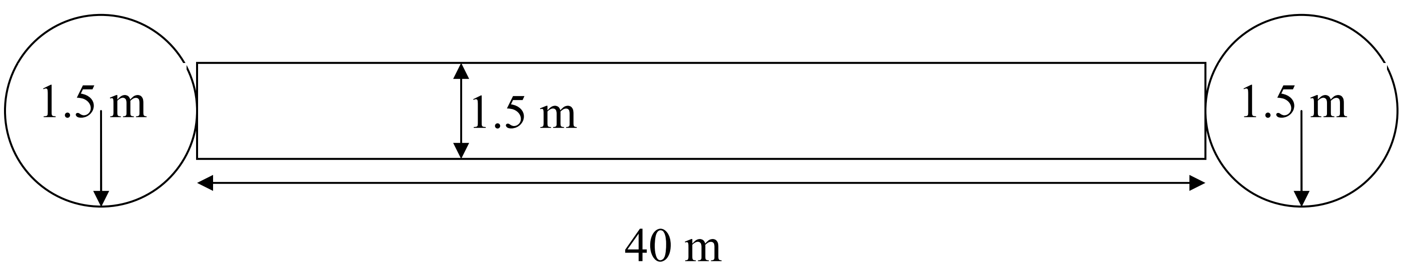

Figure 3. Layout of 1.5-m radius plots for measuring seedling and herbaceous vegetation and 1.5 m × 40 m plot for measuring stem density of shrubs and saplings and presence of specific shrub and herbaceous species. A larger 15-m radius plot also was centered on each 1.5-m radius plot to estimate the percent cover of *Rubus*, grasses, forbs, and ferns.

RESULTS

Phenological Changes

We observed no apparent trends in the height of the tallest plant in each plot for any of the four flowers (Figures 4-7). In fact, the Pearson correlation coefficients indicated shorter heights later in the summer for trillium ($r = -0.171$, $n = 160$), Indian cucumber ($r = -0.004$, $n = 528$), Canada mayflower ($r = -0.222$, $n = 253$), and jack-in-the-pulpit ($r = -0.157$, $n = 46$), but the correlations did not explain much variation in the data (<5%).

However, we did find that the proportion of plots that contained these flowers was greater when we revisited the plot (Table 3). Only sufficient data were available for Indian cucumber and Canada mayflower, but 75-80% of the time we found plants present on the second visit but not on the first visit. In contrast, only 10-20% of the time did we find plants present on both visits.

Table 3. Frequency and percent of plots where flower species were present during both visits, only the first visit, and only the second visit for *Trillium* spp., Canada mayflower, Jack-in-the-pulpit, and Indian cucumber on 22 plots that were visited early (11 May – 7 June) and late (20 July – 22 August) in the summer on 11 state forest lands in Pennsylvania, 2006.

	Both visits		First visit only		Second visit only	
Species	n	%	n	%	n	%
Trillium spp.	8	8.1	12	12.1	79	79.8
Canada mayflower	11	22.5	1	2.0	37	75.5
Jack-in-the-pulpit	1	25.0	3	75.0	0	0.0
Indian Cucumber	0	0.0	2	100.0	0	0.0

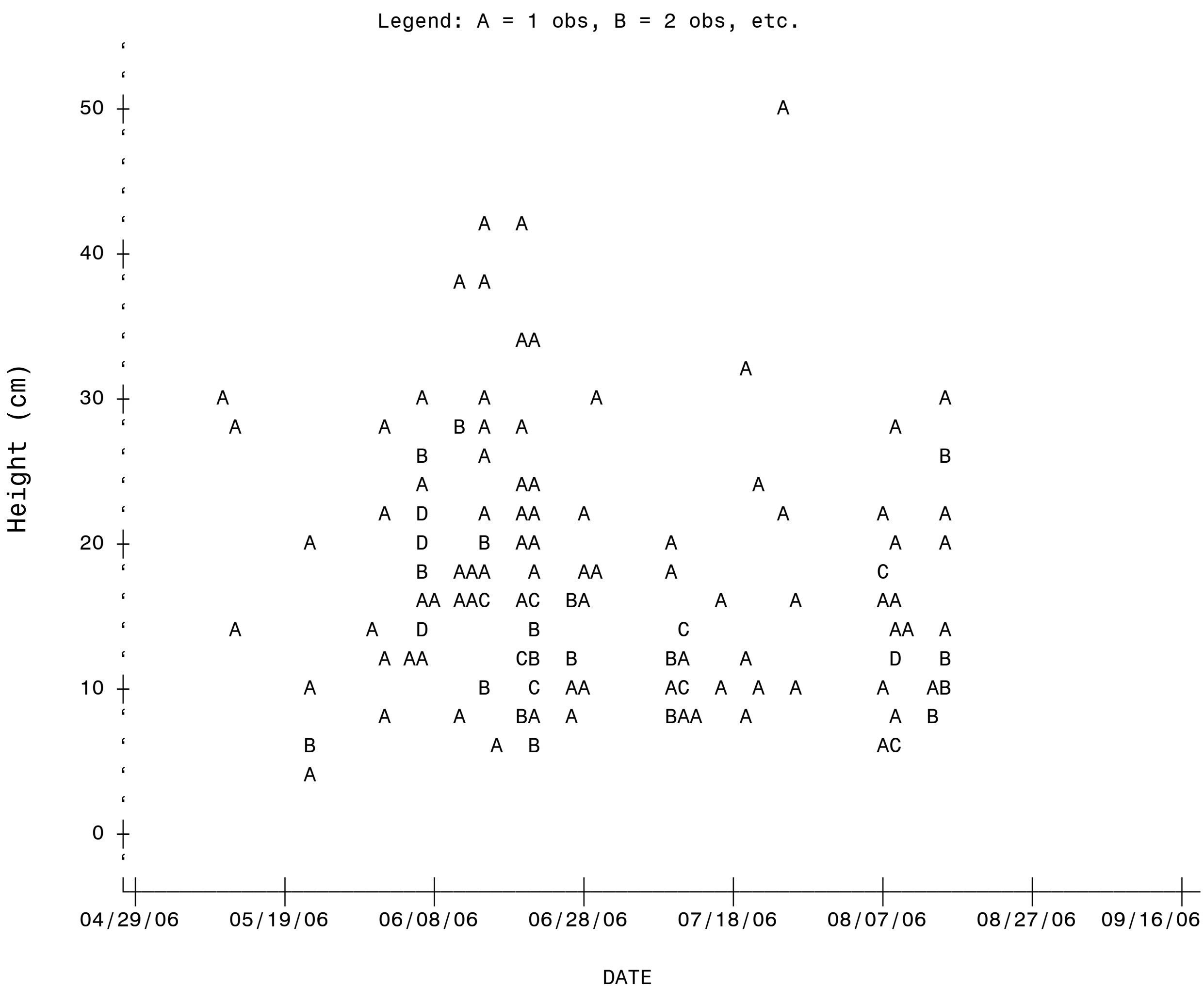

Figure 4. Height of the tallest plant of *Trillium* spp. by date when measurements were recorded on plots from 11 areas enrolled in the Deer Management Assistance Program, Pennsylvania, 2006.

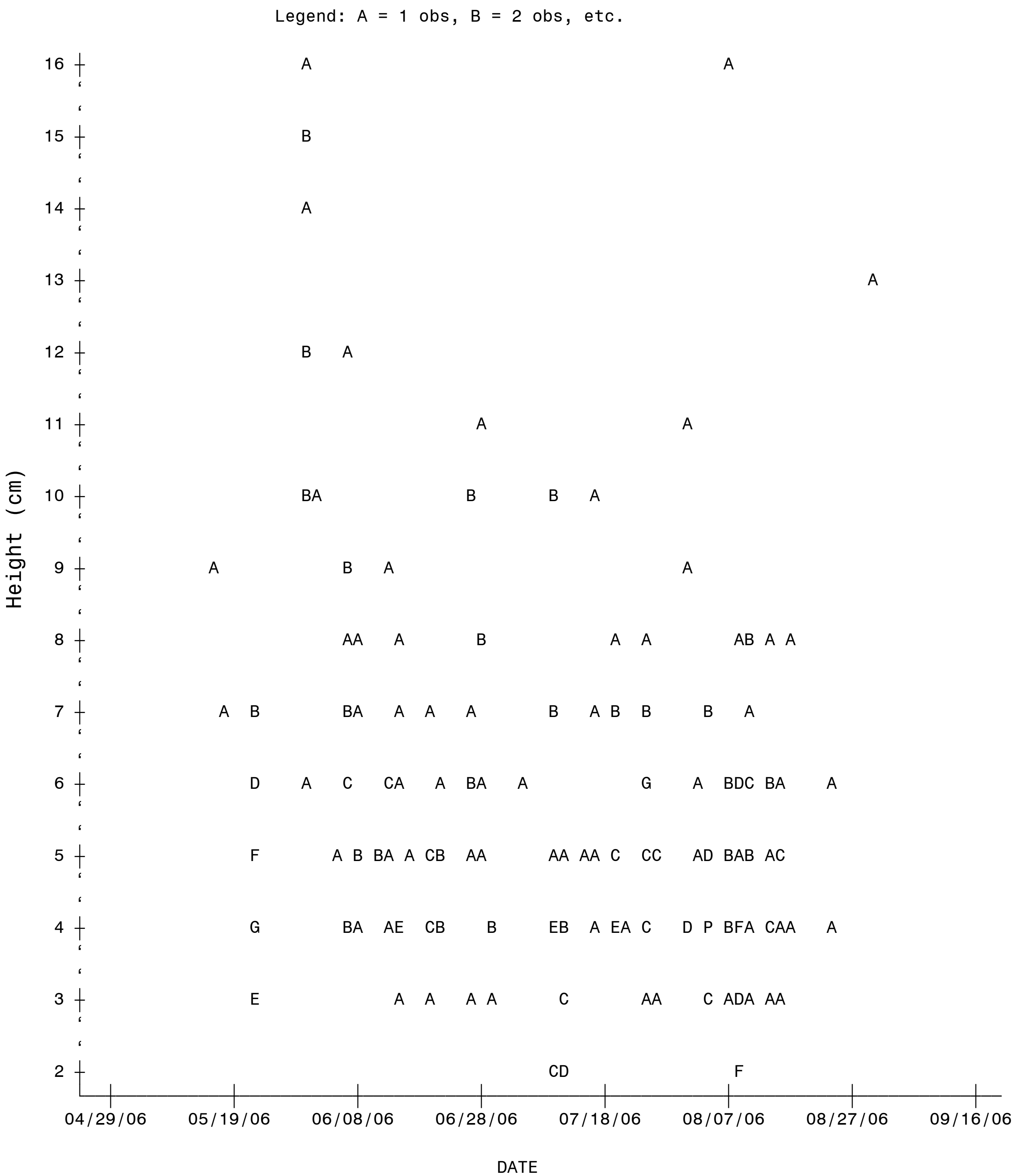

Figure 5. Height of the tallest plant of Canada mayflower (*Maianthemum canadense*) by date when measurements were recorded on plots from 11 areas enrolled in the Deer Management Assistance Program, Pennsylvania, 2006.

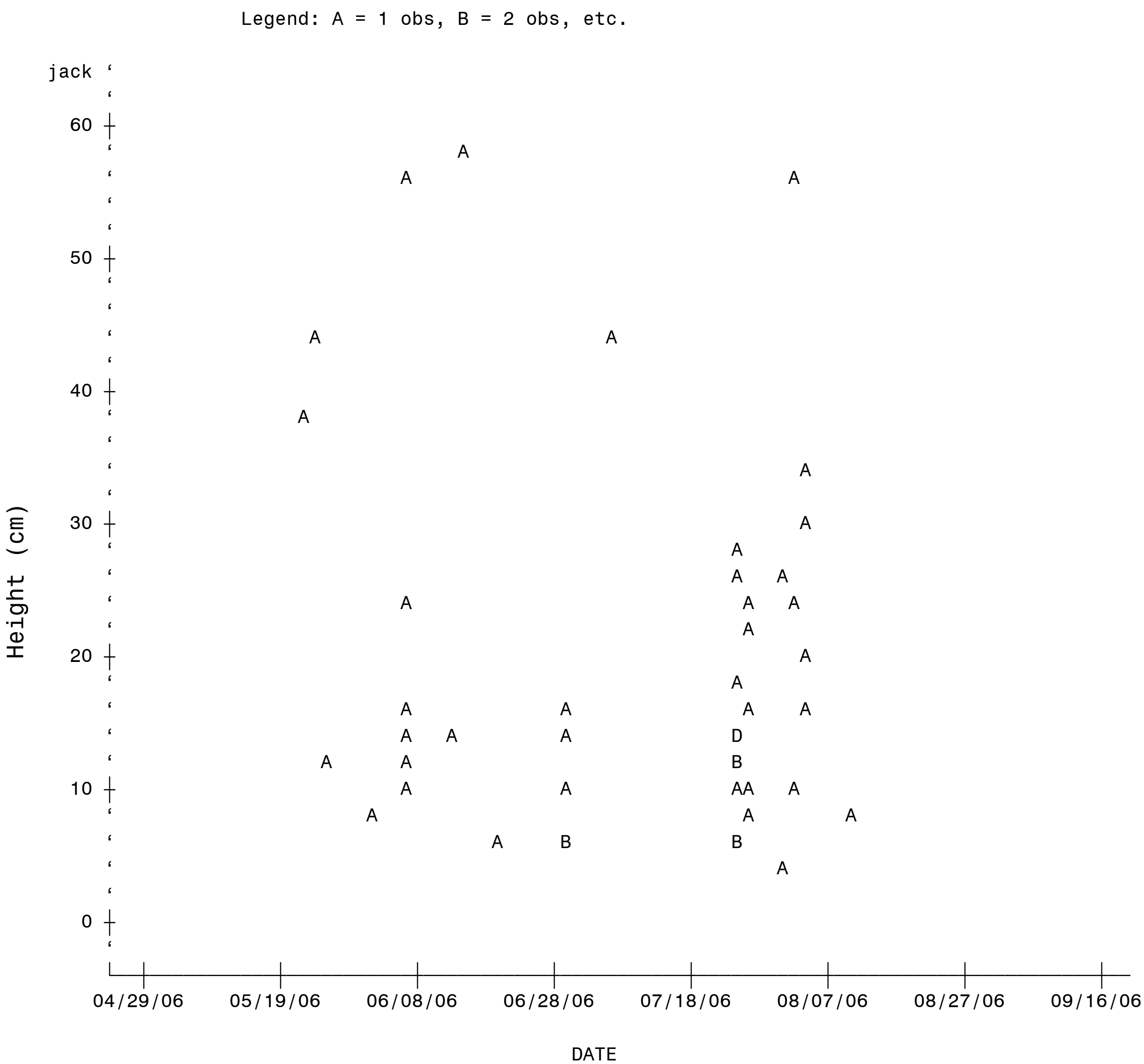

Figure 6. Height of the tallest plant of Jack-in-the-pulpit (*Arisaema triphyllum*) by date when measurements were recorded on plots from 11 areas enrolled in the Deer Management Assistance Program, Pennsylvania, 2006.

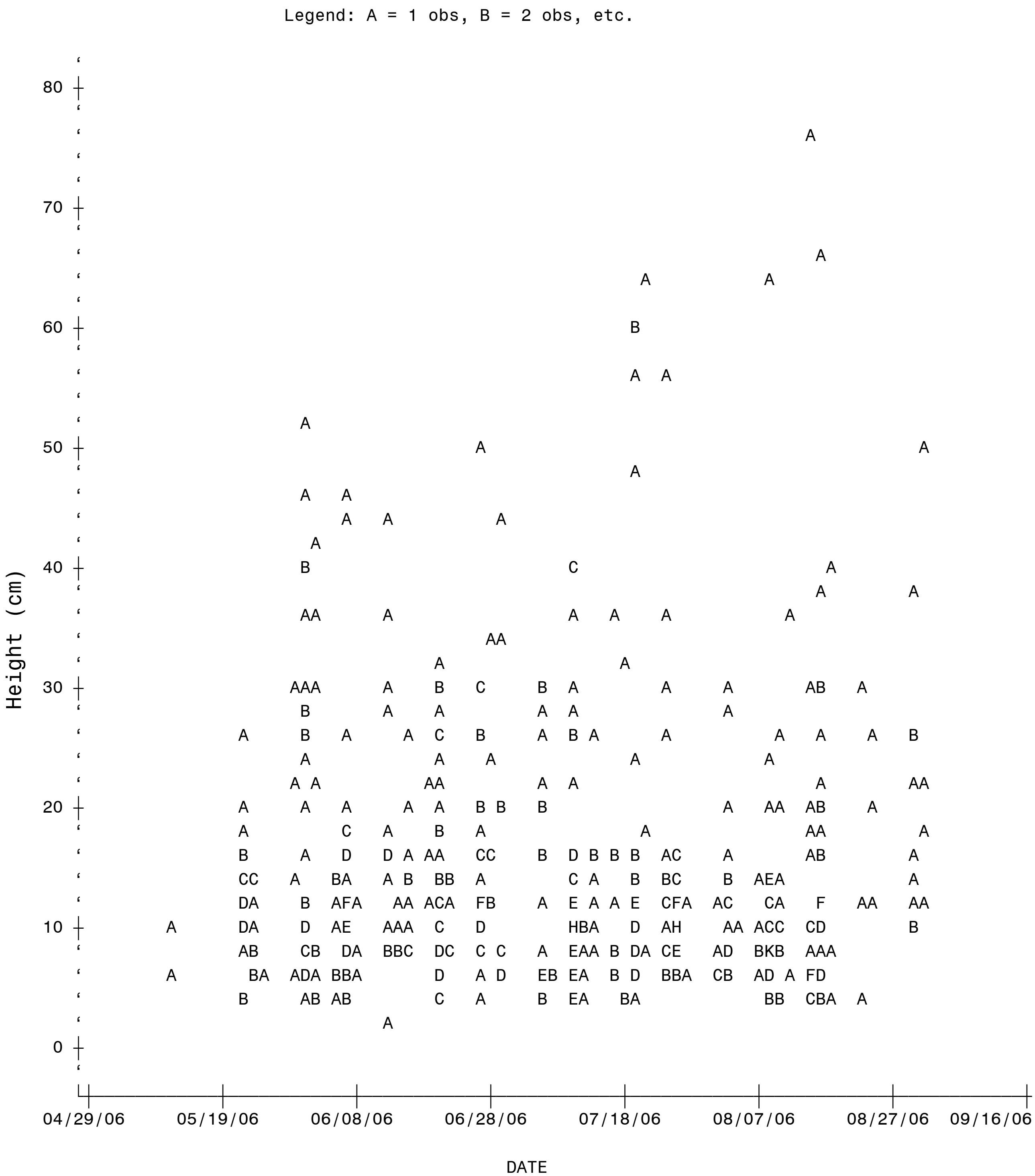

Figure 7. Height of the tallest plant of Indian cucumber (*Medeola virginiana*) by date when measurements were recorded on 11 areas enrolled in the Deer Management Assistance Program, Pennsylvania, 2006.

Basal Area and Tree Density

The variability in estimates of mean basal area was greater among plots than blocks by approximately an order of magnitude (Table 4). Of 2,269 plots, 8.7% had zero basal area and 70.9% had ≤100 feet^2/acre basal area. The overall precision of these estimates was good, CV = 13–22%, and mean basal area ranged from 66–111 feet^2/acre (Table 4).

The basal area of tree species palatable to deer was 47–94% of total basal area, which indicates there are likely sufficient seed sources for palatable tree species.

Table 4. Estimates of mean basal area (feet^2/acre) and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Mean basal area	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	84	17	20	57–123	12	281	0.12
29	Susquehannock	89	20	22	58–136	54	356	0.20
44	Tioga	92	14	16	68–125	11	203	0.38
54	Elk	85	12	14	65–111	82	138	0.42
55	Bald Eagle	111	14	13	87–143	15	199	0.15
99	Tuscarora	85	13	15	63–114	17	166	0.18
266	Delaware	73	14	19	51–104	37	179	0.19
370	Loyalsock	73	16	22	47–111	68	234	0.35
543	Micheaux	66	10	15	49–89	127	101	0.63
704	Sproul	65	15	22	42–101	16	214	0.29
931	Gallitzin	85	14	17	62–118	40	203	0.20

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 5. Estimates of mean basal area (feet^2/acre) of species palatable to white-tailed deer and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Mean basal area	SE	CV	95% CI	Percent of total basal area
18	Moshannon	69	13	19	47–100	82.1
29	Susquehannock	58	16	27	34–98	65.2
44	Tioga	71	14	20	48–105	77.2
54	Elk	73	13	18	52–104	85.9
55	Bald Eagle	98	14	14	74–129	88.3
99	Tuscarora	72	13	18	51–101	84.7
266	Delaware	64	13	20	44–94	87.7
370	Loyalsock	45	16	35	23–87	61.6
543	Micheaux	56	11	19	38–81	84.8
704	Sproul	61	14	23	39–96	93.8
931	Gallitzin	40	13	32	22–74	47.1

Estimates of tree density had less precision (CV = 18–33%) than for basal area. Estimates of percent of plots with <75% stocking ranged from 21% to 66% for the 11 DMAP areas (Table 7).

Table 6. Estimates of mean number of trees/acre and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Mean trees/ acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	149	45	30	83–266	132	2,025	0.19
29	Susquehannock	162	45	28	95–277	359	1,872	0.25
44	Tioga	179	43	24	113–284	98	1,780	0.40
54	Elk	181	40	22	118–279	555	1,623	0.24
55	Bald Eagle	335	60	18	237–475	353	3,611	0.20
99	Tuscarora	149	39	26	89–248	210	1,548	0.24
266	Delaware	165	40	24	103–265	337	1,585	0.19
370	Loyalsock	144	38	26	87–238	246	1,327	0.22
543	Micheaux	126	33	26	76–210	1,283	1,108	0.58
704	Sproul	145	48	33	77–272	99	2,275	0.17
931	Gallitzin	126	31	25	78–204	187	983	0.19

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 7. Percentage of plots with <75% overstory stocking for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Percentage of plots <75% stocking	*n*
18	Moshannon	52.3	260
29	Susquehannock	45.4	130
44	Tioga	44.7	707
54	Elk	50.0	70
55	Bald Eagle	21.5	191
99	Tuscarora	51.7	180
266	Delaware	60.0	90
370	Loyalsock	60.0	120
543	Micheaux	66.0	50
704	Sproul	63.9	371
931	Gallitzin	44.0	100

Sapling and Shrub Stem Densities

The precision of estimates of stem density of shrubs and saplings (>1.5 m tall and <10 cm dbh) were fair (CV = 25–42%) but similar to estimates for tree density (Table 8). Stem densities of interference species represented about 50-75% of all stems (compare Tables 8 and 9). Thirty-two percent of plots had no interference species present, 55% of plots had <400 stems/acre, and 18% of plots had >1,000 stems/acre.

To identify a stem density of interference species (e.g., mountain laurel, striped maple, etc.) that adversely influenced stem densities of other species, we plotted the stem density of non-interference species against interference species (Figure 8). Non-interference species were all other tree species, including commercially desirable species. From this graph, it is evident that increasing stem density of interference species is negatively related to the stem density of non-interference species. We used this graph to exclude plots with ≥1,000 stems/acre of interference species for assessing whether adequate tree regeneration exists because rarely did stem densities of non-interference species exceed 300 stems/acre.

Table 8. Estimates of mean number of stems/acre of shrubs and saplings and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Stems/ acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	497	197	40	235–1,052	4,431	38,669	0.33
29	Susquehannock	2,110	739	35	1,083–4,111	108,500	496,825	0.28
44	Tioga	1,099	359	33	589–2,050	4,936	126,663	0.28
54	Elk	401	167	42	183–879	10,936	28,015	0.27
55	Bald Eagle	727	180	25	450–1,172	3,026	32,381	0.19
99	Tuscarora	856	257	30	482–1,521	6,494	65,896	0.18
266	Delaware	565	191	34	297–1,075	12,724	35,019	0.33
370	Loyalsock	873	228	26	528–1,444	3,813	50,432	0.09
543	Micheaux	785	216	28	462–1,333	5,927	46,710	0.06
704	Sproul	681	243	36	346–1,340	3,928	58,717	0.26
931	Gallitzin	607	230	38	296–1,243	7,128	52,710	0.14

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 9. Estimates of mean number of stems/acre of shrubs and trees identified as interference species to tree seedling growth and associated measures of precision (n = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Stems/ acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	328	48	159	134–807	3,127	25,054	0.36
29	Susquehannock	1,247	39	482	601–2,590	41,621	212,800	0.25
44	Tioga	886	33	290	474–1,654	4,497	82,146	0.39
54	Elk	221	48	106	90–538	4,958	11,201	0.31
55	Bald Eagle	424	33	139	227–793	1,726	19,322	0.18
99	Tuscarora	503	43	219	223–1,138	6,123	47,929	0.23
266	Delaware	387	42	162	176–851	9,535	25,324	0.34
370	Loyalsock	731	29	215	416–1,284	3,291	44,849	0.09
543	Micheaux	363	26	95	219–602	16,525	9,063	0.91
704	Sproul	347	44	152	153–789	2,995	23,039	0.51
931	Gallitzin	461	42	193	209–1,014	4,003	37,364	0.11

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 10. Estimates of mean number of stems/acre of shrubs and trees palatable to white-tailed deer and associated measures of precision (n = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Stems/ acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	279	134	48	115–680	2,485	17,686	0.41
29	Susquehannock	809	382	47	336–1,948	22,632	135,386	0.22
44	Tioga	556	255	46	236–1,310	3,144	63,913	0.35
54	Elk	324	132	41	150–700	5,420	17,528	0.22
55	Bald Eagle	320	124	39	153–666	1,449	15,378	0.19
99	Tuscarora	348	155	44	152–801	1,751	23,994	0.13
266	Delaware	162	79	49	65–402	1,334	6,166	0.19
370	Loyalsock	507	148	29	290–887	2,451	20,884	0.14
543	Micheaux	413	214	52	159–1,074	21,668	45,835	0.24
704	Sproul	242	173	72	68–853	1,688	29,881	0.22
931	Gallitzin	363	119	33	195–679	4,033	14,103	0.29

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

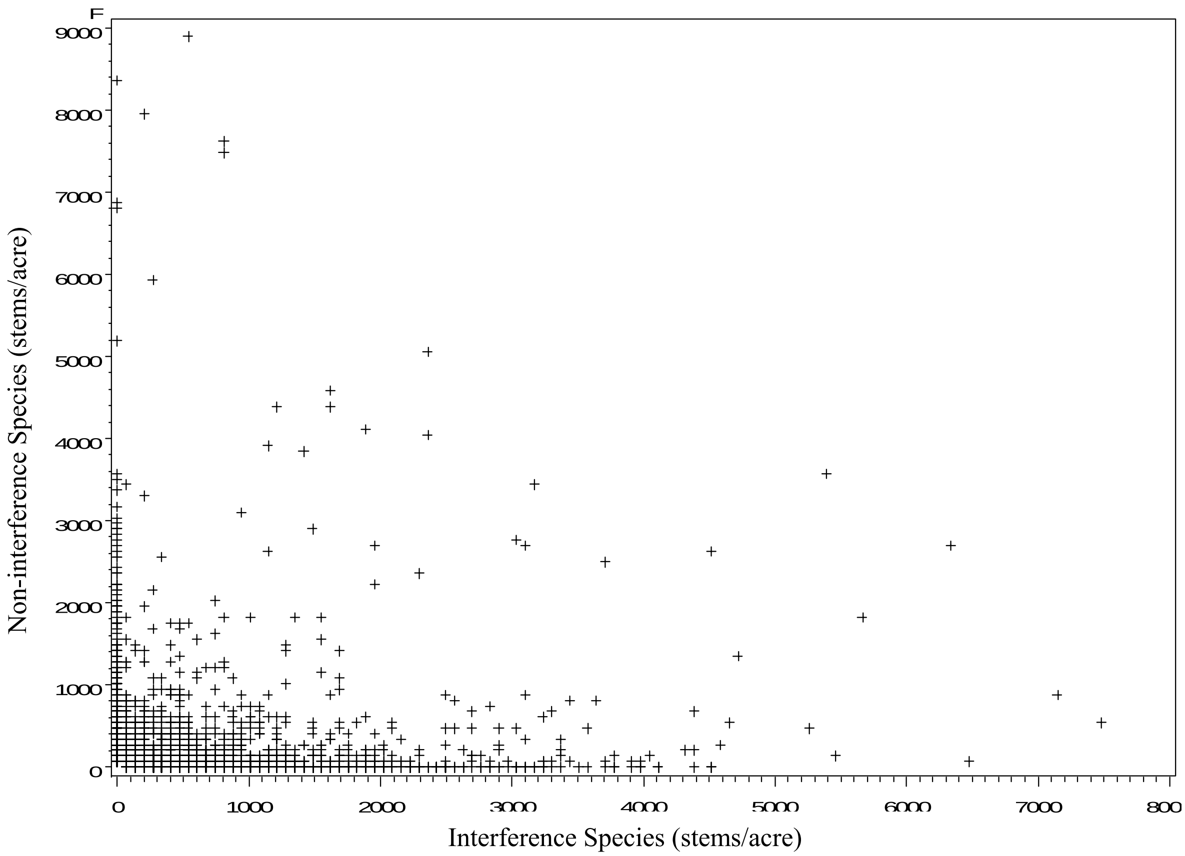

Figure 8. Relationship between stem density of shrub and sapling species identified as interfering with tree seedling growth (see Methods) and all other shrub and sapling species for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

Seedling Stem Densities

The precision of estimates of stem densities of seedlings (30–150 cm tall) was poor (CV = 43–95%) and the variability among blocks was greater than for tree or shrub/sapling densities (Table 11). Forty-five percent of plots had <200 stems/acre and 70% had <1,000 stems/acre.

Estimates of only tree seedlings palatable to white-tailed deer were less precise (CV =48–112%) but these species comprised 50–98% of the stems and usually >80% (Table 12).

Table 11. Estimates of mean number of stems/acre of tree seedlings (30–150 cm tall) and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Stems /acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	1,721	736	43	771–3,843	240,735	361,373	1.93
29	Susquehannock	3,500	2,250	64	1,105–11,084	1,660,150	3,816,861	0.57
44	Tioga	1,175	534	45	503–2,747	31,822	261,174	0.88
54	Elk	954	549	58	334–2,722	144,596	193,146	0.52
55	Bald Eagle	168	159	95	35–805	7,074	19,911	0.71
99	Tuscarora	678	626	92	146–3,157	254,571	200,499	2.29
266	Delaware	535	454	85	126–2,268	94,690	135,376	0.63
370	Loyalsock	1,063	552	52	408–2,770	95,520	233,144	0.49
543	Micheaux	321	278	87	74–1,390	58,456	33,351	0.88
704	Sproul	678	541	80	171–2,686	60,553	247,704	0.95
931	Gallitzin	682	397	58	236–1,967	55,573	116,109	0.48

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 12. Estimates of mean number of stems/acre of tree seedlings (30–150 cm tall) palatable to white-tailed deer and associated measures of precision (*n* = 2,269) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Stems /acre	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	1,360	647	48	561–3,297	159,425	299,126	1.55
29	Susquehannock	1,781	1,329	75	484–6,559	674,434	1,259,123	0.70
44	Tioga	914	476	52	350–2,388	22,104	210,180	0.76
54	Elk	860	515	60	291–2,543	105,637	185,522	0.40
55	Bald Eagle	136	153	112	23–799	6,618	18,403	0.72
99	Tuscarora	521	576	111	90–3,002	227,087	161,258	2.53
266	Delaware	471	428	91	103–2,158	102,018	107,076	0.86
370	Loyalsock	850	466	55	311–2,321	42,255	185,397	0.27
543	Micheaux	315	272	86	73–1,359	55,829	31,983	0.87
704	Sproul	576	420	73	160–2,071	37,469	148,224	0.99
931	Gallitzin	487	328	67	147–1,613	33,509	82,174	0.41

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Presence-Absence Measures

A number of characteristics collected at sample points could be analyzed as presence-absence data. Site characteristics such as the presence of recent (<50 yr) forest fires or recent (<5 yr) logging might influence vegetation characteristics. However, both of these characteristics were evident at <3% of sample points, except on the Susquehannock SF. The DMAP area on the Susquehannock SF was intentionally located on an area with recent logging with the intent to protect tree regeneration; consequently, 10.7% of the area was recently logged.

Percent of plots containing ferns, grass, and forbs was quite high (>50% for most DMAP areas; Table 13). The percent of plots containing *Rubus* was <15%, except on the Susquehannock SF.

Table 13. Percent of plots occupied by fern, *Rubus*, grass, and forbs and the coefficient of variation (CV) for each estimate for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

		Fern		*Rubus*		Grass		Forbs	
DMAP No.	State Forest	Presence (%)	CV	Presence (%)	CV	Presence (%)	CV	Presence (%)	CV
18	Moshannon	85.9	10.5	8.6	99.9	48.9	28.3	79.3	12.1
29	Susquehannock	96.2	6.4	41.5	35.5	63.1	24.4	91.5	9.9
44	Tioga	78.1	14.2	12.2	78.7	37.4	36.8	82.6	9.4
54	Elk	94.3	6.5	8.6	101.8	57.1	23.1	100.0	0.0
55	Bald Eagle	12.0	85.6	0.5	447.2	19.0	57.4	71.0	16.7
99	Tuscarora	37.8	34.8	8.9	93.5	36.1	31.5	68.3	15.0
266	Delaware	74.4	17.9	2.2	213.2	70.0	19	92.2	9.4
370	Loyalsock	89.2	10.7	14.2	76.6	36.7	40.1	90.8	9.6
543	Micheaux	48.0	19.6	0.0	.	4.0	149.1	50.0	14.9
704	Sproul	75.4	15.0	3.1	177.0	49.5	27.1	62.8	14.7
931	Gallitzin	89.0	10.8	3.0	182.6	44.0	31.8	74.0	7.8

Indian cucumber was present on ≥15% of plots on seven of the 11 DMAP areas (Table 14). Jack-in-the-pulpit and trillium were not observed on several study sites and when present occurred on <15% of plots (Table 14). Canada mayflower occurred on most study sites (absent on Elk and Micheaux SF) and when present occurred on 31% of plots (Table 15).

Table 14. Percent of plots occupied by Indian cucumber, Jack-in-the-pulpit, and trillium and the coefficient of variation (CV) for each estimate for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

		Indian cucumber		Jack-in-the-pulpit		Trillium	
DMAP No.	State Forest	Presence (%)	CV	Presence (%)	CV	Presence (%)	CV
18	Moshannon	34.8	40.4	0		13.1	77.5
29	Susquehannock	13.1	82.7	15.38	74.9	4.6	145.1
44	Tioga	16.9	64.6	1.92	218.2	11.2	83.7
54	Elk	22.8	54.6	0.0		0.0	
55	Bald Eagle	7.0	112.7	0.0		0.0	
99	Tuscarora	23.9	49.3	1.67	244.9	0.6	424.3
266	Delaware	43.3	33.6	0.0		3.3	168.2
370	Loyalsock	15.8	73.3	0.83	351.7	5.8	125.9
543	Micheaux	2.0	223.6	0.0		0.0	
704	Sproul	11.8	74.7	0.0		0.8	360.7
931	Gallitzin	20.0	60.6	1.0	316.2	4.0	153.7

Table 15. Percent of plots occupied by Canada mayflower, only flowering plants, and only non-flowering plants and the coefficient of variation (CV) for each estimate for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

		Canada mayflower[a]		Flowering Canada mayflower		Non-flowering Canada mayflower	
DMAP No.	State Forest	Presence (%)	CV	Presence (%)	CV	Presence (%)	CV
18	Moshannon	19.3	59.3	0.0		19.3	59.3
29	Susquehannock	12.3	85.1	0.0		12.3	85.1
44	Tioga	8.9	93.5	1.1	202.3	8.8	95.2
54	Elk	31.4	43.2	1.4	264.6	31.4	43.2
55	Bald Eagle	1.5	258.2	0.0		1.5	258.2
99	Tuscarora	0.0		0.0		0.0	
266	Delaware	27.8	46.1	1.1	301.7	26.7	47.8
370	Loyalsock	3.3	171.8	0.0		3.3	171.8
543	Micheaux	0.0		0.0		0.0	
704	Sproul	1.3	279.4	0.8	360.7	0.8	360.7
931	Gallitzin	17.0	39.7	3.0	175.7	17.0	39.7

[a] Some plots may have contained both flowering and non-flowering plants so the total plots occupied by Canada mayflower is less than or equal to the sum of the percent of plots occupied flowering and non-flowering plants.

The presence of viburnum shrubs, elderberry, and greenbriar was recorded on the 1.5 m × 40 m plots, but generally these species were rarely detected (Table 16). Viburnums occurred on 12% of plots on Micheaux SF, 8% of plots on Gallitzin SF, and 6% of plots on Tioga SF but occurred <4% of plots on all other study sites and were never detected on the Susquehannock, Elk, and Loyalsock SF. Elderberry was only detected on the Gallitzin and Tioga SF but only occurred on ≤1% of the plots. Greenbriar was absent on Susquehannock, Elk, and Loyalsock SF and occurred on <11% of plots on other study sites.

Table 16. Percent of plots occupied by viburnum shrubs (*Viburnum* spp.), elderberry (*Sambucus canadensis*), and greenbriar (*Smilax* spp.) and the coefficient of variation (CV) for each estimate for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

		Viburnum		Elderberry		Greenbriar	
DMAP No.	State Forest	Presence (%)	CV	Presence (%)	CV	Presence (%)	CV
18	Moshannon	0.7	388	0.0		4.1	154
29	Susquehannock	0.0		0.0		0.0	
44	Tioga	6.2	115	0.1	851	0.4	491
54	Elk	0.0		0.0		0.0	
55	Bald Eagle	0.5	459	0.0		8.0	100
99	Tuscarora	4.4	130	0.0		11.1	83
266	Delaware	1.1	302	0.0		1.1	302
370	Loyalsock	0.0		0.0		0.0	
543	Micheaux	12.0	81	0.0		6.0	129
704	Sproul	1.8	225	0.0		2.1	239
931	Gallitzin	8.0	107	1.0	316	4.0	144

Percent Cover

Estimates of percent cover had fair to poor precision, especially for estimates of grass cover and *Rubus* because they were relatively sparse (Tables 17-20). *Rubus* would only be expected to occur on plots with substantial exposure to the sun, which is why it was oftentimes absent (<2% of sites contained ≥20% *Rubus* cover; Table 21). Grass had <20% coverage on 92% of plots and forbs had <20% coverage on 77% of plots. Ferns had >30% coverage on 32% of plots.

Table 17. Estimates of percent cover of ferns (n = 2,350) with measures of precision for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Percent Cover	SE	CV	95% CI
18	Moshannon	30.7	7.128	23.2	19.6–48.1
29	Susquehannock	37.6	9.600	25.5	23.0–61.5
44	Tioga	18.5	6.729	36.4	9.3–36.9
54	Elk	22.2	5.448	24.6	13.8–35.6
55	Bald Eagle	3.2	3.787	116.8	0.5–19.97
99	Tuscarora	8.3	5.773	69.8	2.4–28.4
266	Delaware	10.0	5.191	51.8	3.9–26.1
370	Loyalsock	14.9	5.421	36.3	7.5–29.8
543	Micheaux	1.4	0.754	55.2	0.5–3.8
704	Sproul	19.9	6.424	32.3	10.7–36.9
931	Gallitzin	12.4	3.630	29.3	7.1–21.7

Table 18. Estimates of percent cover of *Rubus* (n = 2,350) with measures of precision for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Percent Cover	SE	CV	95% CI
18	Moshannon	0.7	0.857	132.5	0.1–4.7
29	Susquehannock	4.7	3.438	72.6	1.3–17.0
44	Tioga	1.0	1.948	195.5	0.1–11.7
54	Elk	0.6	1.135	203.7	0.1–6.9
55	Bald Eagle	0.0	0.056	447.2	0.0–0.4
99	Tuscarora	0.5	0.745	160.6	0.1–4.2
266	Delaware	1.0	3.017	300.0	0.1–19.7
370	Loyalsock	2.2	3.253	151.6	0.3–18.3
543	Micheaux	0.0			
704	Sproul	0.3	1.135	400.5	0.0–7.7
931	Gallitzin	0.5	1.423	309.4	0.0–9.3

Table 19. Estimates of percent cover of grass (n = 2,350) with measures of precision for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Percent Cover	SE	CV	95% CI
18	Moshannon	6.4	3.954	61.8	2.1–19.5
29	Susquehannock	9.3	5.611	60.4	3.1–27.7
44	Tioga	2.5	2.522	100.6	0.5–12.9
54	Elk	4.1	2.046	50.0	1.6–10.3
55	Bald Eagle	2.4	2.410	102.8	0.4–12.4
99	Tuscarora	3.5	3.009	86.8	0.8–15.1
266	Delaware	17.6	4.772	27.0	10.5–29.7
370	Loyalsock	2.9	2.421	83.0	0.7–12.1
543	Micheaux	1.0	1.795	179.5	0.1–10.5
704	Sproul	8.2	4.659	57.1	2.9–23.1
931	Gallitzin	7.6	4.142	54.4	2.8–20.7

Table 20. Estimates of percent cover of forbs (n = 2,350) with measures of precision for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Percent Cover	SE	CV	95% CI
18	Moshannon	18.4	4.597	25.0	11.4–29.8
29	Susquehannock	4.5	1.791	39.4	2.2–9.6
44	Tioga	14.3	4.655	32.7	7.6–26.6
54	Elk	15.4	2.930	19.0	10.7–22.3
55	Bald Eagle	2.6	1.314	50.6	1.0–6.6
99	Tuscarora	9.1	3.458	37.8	4.5–18.7
266	Delaware	35.4	7.721	21.8	23.2–54.1
370	Loyalsock	22.5	6.510	29.0	12.9–39.2
543	Micheaux	9.3	2.691	28.9	5.3–16.2
704	Sproul	11.4	3.663	32.1	6.2–21.1
931	Gallitzin	11.4	2.839	25.0	7.0–18.4

Table 21. Distribution of the number of sites with grouped levels of percent cover of fern, forbs, grass, and *Rubus* (*n* = 2,350) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

Percent cover	Fern	Forb	Grass	*Rubus*
<10%	54.8	56.8	86.2	97.6
10-<20%	13.0	19.5	5.9	1.2
20-<30%	7.4	8.9	2.4	0.3
30-<40%	5.7	5.0	1.4	0.3
40-<50%	6.5	3.2	1.9	0.2
50-<60%	3.8	2.3	0.5	<0.1
60-<70%	2.8	1.9	0.3	0.0
70-<80%	2.0	1.3	0.3	0.2
80-<90%	2.1	0.6	0.3	0.1
90-<100%	1.6	0.6	0.6	0.1
100%	0.3	0.0	0.0	0.0

Flower Counts

Indian cucumber was the only flower found on all study sites (Tables 22 and 23). Jack-in-the-pulpit was not observed on 6 study sites and trillium were not observed on three study sites (Table 22). Canada mayflower was not observed on two study sites and the number of flowering plants was extremely low (Table 23).

Table 22. Mean number of plants of Indian cucumber, Jack-in-the-pulpit, and trillium (*n* = 2,350) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Species	No. plants	SE	CV	95% LCL	95% UCL
18	Moshannon	Indian cucumber	2.5	1.651	66.1	0.8	8.1
29	Susquehannock	Indian cucumber	0.8	1.137	146.4	0.1	6.3
44	Tioga	Indian cucumber	1.1	1.164	109.9	0.2	6.1
54	Elk	Indian cucumber	0.7	0.418	63.6	0.2	2.1
55	Bald	Indian cucumber	0.11	0.207	196.9	0.0	1.24
99	Tuscarora	Indian cucumber	1.4	1.165	82.4	0.3	5.8
266	Delaware	Indian cucumber	2.9	1.738	59.8	1.0	8.6
370	Loyalsock	Indian cucumber	1.6	2.088	129.5	0.2	11.3
543	Micheaux	Indian cucumber	0.0	0.045	223.6	0.0	0.3
704	Sproul	Indian cucumber	0.7	0.944	145.5	0.1	5.2
931	Gallitzin	Indian cucumber	5.4	6.366	118.4	0.9	33.7
18	Moshannon	Jack-in-the-Pulpit	0				
29	Susquehannock	Jack-in-the-Pulpit	0.5	0.633	118.4	0.1	3.4
44	Tioga	Jack-in-the-Pulpit	0.1	0.372	316.1	0.0	2.5
54	Elk	Jack-in-the-Pulpit	0				
55	Bald	Jack-in-the-Pulpit	0				
99	Tuscarora	Jack-in-the-Pulpit	0.1	0.176	287.3	0.0	1.1
266	Delaware	Jack-in-the-Pulpit	0				
370	Loyalsock	Jack-in-the-Pulpit	0.0	0.015	351.7	0.0	0.1
543	Micheaux	Jack-in-the-Pulpit	0				
704	Sproul	Jack-in-the-Pulpit	0				
931	Gallitzin	Jack-in-the-Pulpit	0.0	0.095	316.2	0.0	0.6
18	Moshannon	Trillium	0.2	0.162	106.8	0.0	0.8
29	Susquehannock	Trillium	0.1	0.105	210.3	0.0	0.6
44	Tioga	Trillium	0.1	0.19	131.7	0.0	1.0
54	Elk	Trillium	0				
55	Bald	Trillium	0				
99	Tuscarora	Trillium	0.0	0.071	424.3	0.0	0.5
266	Delaware	Trillium	0.0	0.054	194.5	0.0	0.3
370	Loyalsock	Trillium	0.1	0.062	134.4	0.0	0.3
543	Micheaux	Trillium	0				
704	Sproul	Trillium	0.0	0.154	521.7	0.0	1.1
931	Gallitzin	Trillium	0.1	0.088	194.9	0.0	0.5

Table 23. Mean number of plants of Canada mayflower (all plants, only flowering plants, and only non-flowering plants; *n* = 2,350) for areas enrolled in the Deer Management Assistance Program (DMAP) on 11 state forests, Pennsylvania, 2006.

DMAP No.	State Forest	Flowering Status	No. plants	SE	CV	95% LCL	95% UCL
18	Moshannon	All plants	2.2	2.025	92.1	0.5	10.2
29	Susquehannock	All plants	1.1	1.042	95.1	0.2	5.3
44	Tioga	All plants	0.8	1.39	167.8	0.1	8.0
54	Elk	All plants	4.1	2.588	63.3	1.3	12.8
55	Bald	All plants	0.2	0.604	298.1	0.0	3.93
99	Tuscarora	All plants	0				
266	Delaware	All plants	2.1	1.545	72.4	0.6	7.6
370	Loyalsock	All plants	0.2	0.421	194.4	0.0	2.5
543	Micheaux	All plants	0				
704	Sproul	All plants	0.5	2.421	521.6	0.0	16.7
931	Gallitzin	All plants	8.8	6.11	69.8	2.6	30.1
18	Moshannon	Flowering	0				
29	Susquehannock	Flowering	0				
44	Tioga	Flowering	0.0	0.07	291.9	0.0	0.5
54	Elk	Flowering	0.0	0.019	264.6	0.0	0.1
55	Bald	Flowering	0				
99	Tuscarora	Flowering	0				
266	Delaware	Flowering	0.1	0.352	301.7	0.0	2.3
370	Loyalsock	Flowering	0				
543	Micheaux	Flowering	0				
704	Sproul	Flowering	0.2	0.844	457	0.0	5.8
931	Gallitzin	Flowering	0.1	0.135	225.7	0.0	0.8
18	Moshannon	Non-flowering	2.2	2.025	92.1	0.5	10.2
29	Susquehannock	Non-flowering	1.1	1.042	95.1	0.2	5.3
44	Tioga	Non-flowering	0.8	1.38	171.5	0.1	8.0
54	Elk	Non-flowering	4.1	2.587	63.4	1.3	12.8
55	Bald	Non-flowering	0.2	0.604	298.1	0.0	3.93
99	Tuscarora	Non-flowering	0				
266	Delaware	Non-flowering	2.0	1.527	75.7	0.5	7.6
370	Loyalsock	Non-flowering	0.2	0.421	194.4	0.0	2.5
543	Micheaux	Non-flowering	0				
704	Sproul	Non-flowering	0.3	1.607	575	0.0	11.1
931	Gallitzin	Non-flowering	8.7	6.066	69.8	2.5	29.9

Modeling Counts of Indian Cucumber

We modeled the counts of Indian cucumber using a zero-inflated Poisson regression model, because >80% of plots had zero plants present. We found that the best model of number of plants present included percent fern cover and an indicator variable for whether the overstory stocking was >75% (0 = $\leq$75%; 1 = >75%; Table 24).

The best model indicated the number of plants declined with greater overstory stocking and fern cover. The inflation probability for zero counts was 0.8181 (SE = 0.00801), which indicates that 82% of plots had zero counts and the remaining 18% of plots were modeled using Poisson regression in which counts were a function of fern cover and overstory stocking (Table 25).

Table 24. Differences in Akaike's Information Criterion (ΔAIC) for models of counts of Indian cucumber on 1.5-m radius plots.

Model description	No. parameters	ΔAIC[a]
Fern and overstory	5	0.0
Overstory only	4	9.2
Intercept only	3	70.6
Fern only	4	75.2

[a] ΔAIC = AIC value of given model minus the AIC value for the model with the lowest value.

Table 25. Parameter estimates for the best model of Indian cucumber on 1.5-m radius plots.

Parameter	Estimate	SE
Intercept	0.4239	0.19910
Slope for fern percent cover	-0.1775	0.05338
Slope for overstory stocking	-0.1925	0.03360
Inflation probability	1.5037	0.05384
Variance of random error associated with blocks	6.0324	0.88160

Flower Heights

The precision of estimates of mean heights of the tallest plant in each plot (when present) were fair to poor for Indian cucumber and Jack-in-the pulpit (CV = 28.3–64.3%; Tables 26 and 27) and good to fair for Canada mayflower and trillium (CV = 10.6–59.1%; Tables 28 and 29). Because plants had to be present before a measurement could be recorded for each plot, sample sizes were limited on some study areas, especially for Jack-in-the-pulpit, and estimates of variance across blocks or plots were not estimable in all cases (e.g., see Jack-in-the-pulpit measurements for Tuscarora SF; Table 27).

Table 26. Mean heights and measures of precision for Indian cucumber plants.

DMAP No.	State Forest	Mean height (cm)	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	11.2	4.25	38.0	5.4–22.9	0.81	17.94	0.05
29	Susquehannock	21.3	11.62	54.5	7.8–58.0	28.92	117.05	0.25
44	Tioga	16.2	6.04	37.2	8.0–32.9	1.41	35.64	0.04
54	Elk	10.0	3.46	34.7	5.2–19.3	1.43	11.77	0.12
55	Bald Eagle	12.9	8.15	63.2	4.1–40.2	5.27	63.52	0.08
99	Tuscarora	13.2	6.56	49.6	5.3–33.2	2.40	42.27	0.06
266	Delaware	12.0	4.80	39.9	5.7–25.6	3.44	22.38	0.15
370	Loyalsock	12.6	5.38	42.8	5.6–28.1	1.68	28.16	0.06
543	Micheaux	7.0						
704	Sproul	16.4	6.23	37.9	8.0–33.7	4.13	36.30	0.11
931	Gallitzin	11.3	3.20	28.3	6.5–19.4	0.98	9.92	0.10

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 27. Mean heights and measures of precision for Jack-in-the-pulpit plants.

DMAP No.	State Forest	Mean height (cm)	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon							
29	Susquehannock	17.7	6.84	38.7	8.5–36.8	4.94	43.65	0.11
44	Tioga	20.7	13.31	64.3	6.5–65.6	47.59	132.48	0.36
54	Elk							
55	Bald Eagle							
99	Tuscarora	21.0	10.58	50.4	8.3–53.3	134.33		
266	Delaware							
370	Loyalsock	43.0						
543	Micheaux							
704	Sproul	7.0						
931	Gallitzin	38.0						

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 28. Mean heights and measures of precision for Canada mayflower plants.

DMAP No.	State Forest	Mean height (cm)	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	4.6	1.03	22.5	3.0–7.1	0.07	1.03	0.07
29	Susquehannock	5.3	0.61	11.6	4.2–6.6	0.16	0.27	0.60
44	Tioga	6.2	1.09	17.7	4.4–8.7	0.18	1.07	0.17
54	Elk	4.6	1.07	23.1	3.0–7.2	0.38	1.09	0.35
55	Bald Eagle	5.0	0.53	10.6	4.1–6.2	0.33		
99	Tuscarora							
266	Delaware	5.4	0.90	16.7	3.9–7.5	0.12	0.77	0.16
370	Loyalsock	7.8	2.02	25.8	4.8–12.9	2.19	2.25	0.98
543	Micheaux							
704	Sproul	7.8	1.43	18.3	5.5–11.1	2.34		
931	Gallitzin	4.3	0.56	12.9	3.4–5.6	0.34	0.07	4.60

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Table 29. Mean heights and measures of precision for trillium plants.

DMAP No.	State Forest	Mean height (cm)	SE	CV	95% CI	Block variance	Plot variance	Block:plot variance ratio[a]
18	Moshannon	13.5	2.69	19.9	9.2–19.9	1.79	6.48	0.28
29	Susquehannock	17.3	10.19	59.1	5.9–50.4	5.60	99.25	0.06
44	Tioga	17.9	4.28	23.8	11.3–28.4	1.05	17.59	0.06
54	Elk							
55	Bald Eagle							
99	Tuscarora							
266	Delaware	31.3	16.96	54.3	11.6–84.6	351.56	6.25	56.25
370	Loyalsock	11.5	2.10	18.3	8.0–16.4	1.35	3.35	0.40
543	Micheaux							
704	Sproul	23.7	5.16	21.8	15.5–36.1	28.78		
931	Gallitzin	10.8	3.96	36.5	5.4–21.7	22.03	0.25	88.11

[a] The variance ratio is the ratio of estimated variances without correcting for sample size to remove the effect of sampling intensity.

Advanced Tree Regeneration

The precision of index values for advanced tree regeneration was fair to poor for most study areas, but the percentage of plots adequately stocked was quite low (≤20%; Table 30). The Susquehannock State Forest had the greatest percentage of plots adequately stocked (72.4%,) and lowest CV (26%). On most study areas, most blocks lacked adequate advanced regeneration (Table 31). Therefore, even though the precision of this measure was poor, there is potential for dramatic increases in the percent of plots adequately stocked. We found that reducing the weighting of tree seedlings (30–150 cm tall) from 20 to 10 had little effect on results.

Table 30. Percent of plots adequately stocked with advanced regeneration for plots with <75% overstory stocking, <25% fern cover, and <1,000 stems/acre of interference tree or shrub species. Each sapling (>1.5 m tall and <10 cm dbh) is given a weighted count of 50 and each seedling (30–150 cm tall) is given a weighted count of 20.

DMAP No.	State Forest	Percent adequately stocked	SE	CV	95% CI
18	Moshannon	31.2	15.9	50.3	12.3–79.3
29	Susquehannock	72.4	19.1	26.0	43.8–119.7
44	Tioga	19.2	13.7	70.2	5.6–66.6
54	Elk	10.5	11.3	106.9	1.9–58.0
55	Bald Eagle	11.8	10.8	84.1	2.8–49.4
99	Tuscarora	21.1	8.2	38.8	10.1–43.9
266	Delaware	16.9	11.0	64.4	5.3–53.8
370	Loyalsock	14.8	10.3	68.8	4.4–50.2
543	Micheaux	20.8	9.8	46.8	8.7–49.7
704	Sproul	20.2	12.5	61.2	6.7–61.0
931	Gallitzin	12.5	5.8	46.3	5.3–29.6

Table 31. Distribution of the percent of plots within each block that are adequately stocked for plots with <75% overstory stocking, <25% fern cover, and <1,000 stems/acre of interference tree or shrub species.

		Percent of plots adequately stocked per block										
DMAP No.	State Forest	0	10	20	30	40	50	60	70	80	90	100
18	Moshannon	13	0	2	2	2	3	0	0	0	0	5
29	Susquehannock	0	1	1	1	0	1	1	2	0	0	6
44	Tioga	40	2	3	6	2	3	4	1	1	0	3
54	Elk	5	0	0	1	1	0	0	0	0	0	0
55	Bald Eagle	12	0	2	0	1	0	0	0	0	0	1
99	Tuscarora	10	1	2	2	0	1	0	0	0	0	2
266	Delaware	4	2	1	1	0	0	1	0	0	0	0
370	Loyalsock	6	1	2	2	1	0	0	0	0	0	0
543	Micheaux	1	2	0	1	1	0	0	0	0	0	0
704	Sproul	19	2	4	5	1	3	1	0	2	0	0
931	Gallitzin	8	0	1	0	0	0	0	0	0	0	1

Browsing of Tree Seedlings

Browsing of tree seedlings is difficult to interpret because seedlings have to be present before browsing can be measured. Consequently, on five of the 11 study sites, the proportion of unpalatable species browsed was greater than for palatable species. In general, the precision of these estimates is good to fair (CV = 13.9–76.1).

Table 32. Proportion (*p*) of tree seedlings (30–150 cm tall) with evidence of deer browsing with coefficient of variation (CV) for all tree species, only species palatable to deer, and only unpalatable species.

DMAP No.	State Forest	All species		Palatable species		Unpalatable species	
		p	CV	*p*	CV	*p*	CV
18	Moshannon	0.47	38.7	0.50	36.5	0.29	76.1
29	Susquehannock	0.41	26.2	0.36	38.0	0.47	37.3
44	Tioga	0.50	33.2	0.48	39.4	0.55	33.8
54	Elk	0.77	13.9	0.78	14.8	0.6	72.7
55	Bald Eagle	0.49	46.5	0.47	57.5	0.46	68.0
99	Tuscarora	0.51	35.2	0.43	64.8	0.66	36.4
266	Delaware	0.63	46.3	0.55	52.3	1.00	
370	Loyalsock	0.76	19.8	0.74	21.9	0.79	14.5
543	Micheaux	0.78	20.4	0.79	20.6	0.00	
704	Sproul	0.42	40.1	0.46	37.7	0.23	71.0
931	Gallitzin	0.59	16.6	0.58	21.7	0.82	16.7

Statistical Power to Detect Changes

Mean heights of the tallest Indian cucumber plant in each plot where the species was present ranged from 7.0 to 21.3 cm (Table 26), whereas the reported height for this species is 20–90 cm (http://plants.usda.gov). We estimated that a repeated sampling design could have a ≥80% chance (statistical power) of detecting increases of 8–30 cm depending on the DMAP area (Figure 9).

The statistical power to detect increases in stem density of tree seedlings (30–150 cm tall) was poor, but areas with low stem densities had a ≥80% chance of detecting increases of ≤800 stems/acre (Bald Eagle and Micheaux state forests; Figure 10). Areas with current stem densities of >1,000 stems/acre had little chance of even detecting increases of >1,500 stems/acre (Table 11).

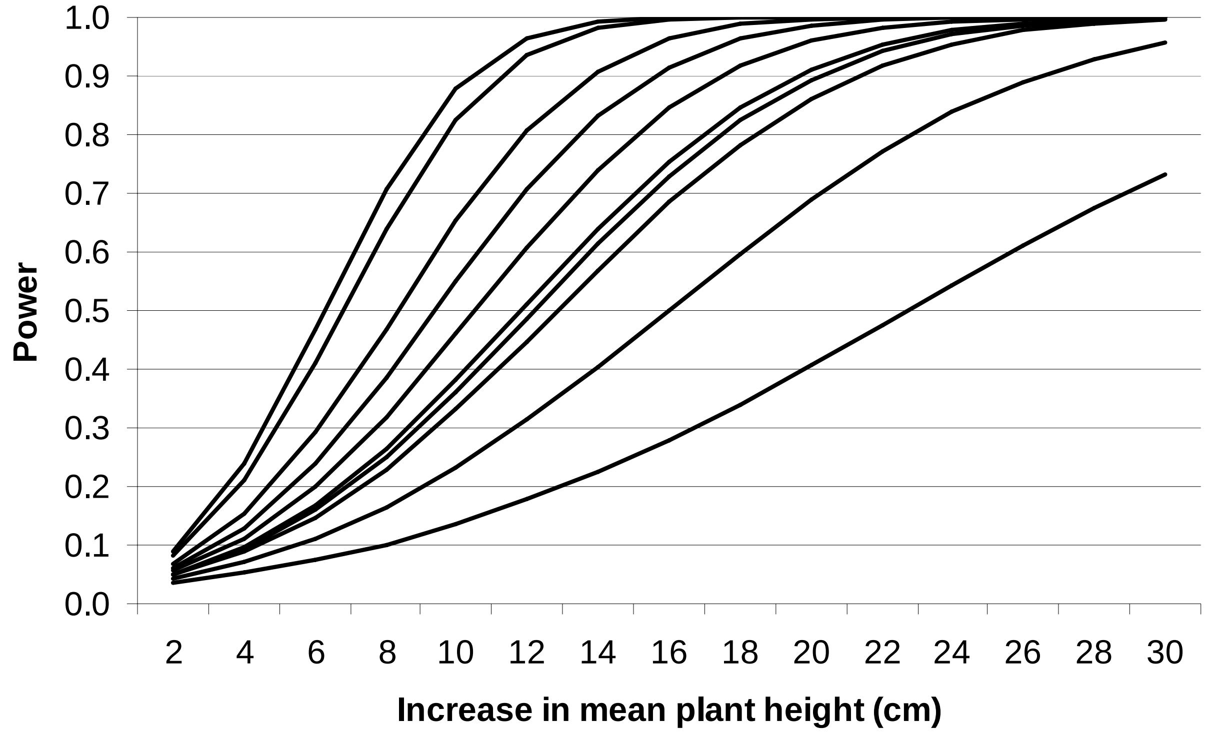

Figure 9. Statistical power (α = 0.05) to detect an increase in mean height of Indian cucumber assuming a normal distribution and variances remain constant during the two sampling periods. Power curves (bottom to top) are for areas enrolled in the Deer Management Assistance Program on Susquehanna, Bald Eagle, Tuscarora, Sproul, Tioga, Loyalsock, Delaware, Moshannon, Elk, and Gallitzin state forests.

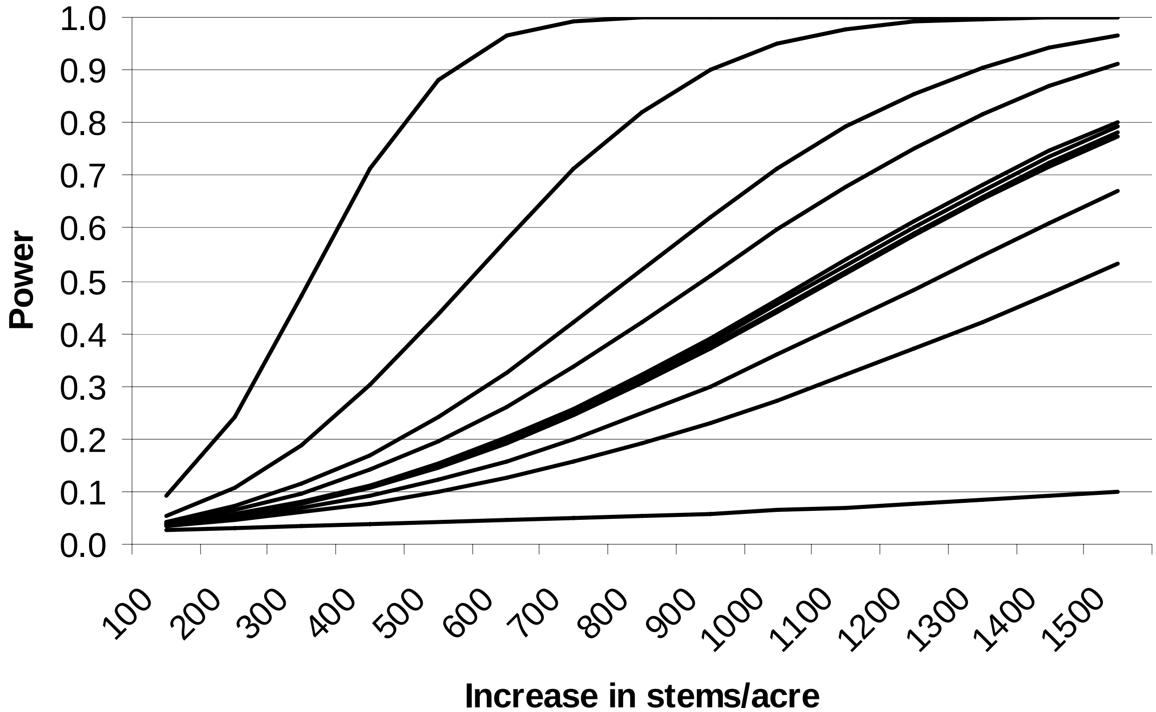

Figure 10. Statistical power (α = 0.05) to detect an increase in stem density of tree seedlings (30–150 cm tall) assuming a normal distribution and variances remain constant during the two sampling periods. Power curves (bottom to top) are for areas enrolled in the Deer Management Assistance Program on Susquehanna, Moshannon, Tuscarora, Loyalsock, Elk, Sproul, Tioga, Delaware, Gallitzin, Micheaux, and Bald Eagle state forests.

DISCUSSION

Improvements to Sampling Design

The sampling design employed for this study was a two-stage design in which square-mile blocks were randomly selected, and then within each block 10 sample points were visited for data collection. Thus, there were two sources of variability that needed to be accounted for in the estimation of variances of parameters: variability among blocks and variability among sample points (within blocks).

A consistent pattern among all measurements was that variability among blocks was almost inconsequential compared to the variability among sample points (block:plot variance ratios <<1). Thus, our recommendation for more efficient sampling is to reduce the number of blocks visited and to increase the number of sample points within each block. In 2006, we sampled 54–100% of the blocks in each DMAP area.

For DMAP areas of <20 square miles, we recommend visiting five blocks (sampling fraction ≥25%). For larger DMAP areas, visit an additional block for every additional 10 square miles of area above 20 square miles (sampling fraction ≥20% for 30 mi^2, ≥16% for 50 mi^2, etc.). Also, we recommend each block contain 20 sample points (instead of 10).

Reducing the number of blocks sampled and increasing the number of sample sites within each block has two advantages. First, the ratio of block:plot variances will become more equal (closer to 1.0), which should result in about the same overall precision as observed for this study. For example, estimates of seedling stems densities (0.30–1.5 m tall) from 1.5-m radius plots had CVs of 35–84% (168–3,500 stems/acre; Table 11). If we assume the same variances but reduce the sampling fraction of blocks to 0.25 and increase the number of sample points per block to 20 we maintain CVs at 33–80% (Table 30).

Second, a 2-person field team visited about 8 blocks per week in 2006. Given that sampling time at each plot is only about 15 minutes and a significant amount of time is walking between blocks, we estimate that a trained crew could complete five blocks in three or four days if 20 plots per block are sampled. However, because the overall number of blocks visited is reduced the overall sampling effort would be substantially less than was observed during our field work. Each of eight of the 11 DMAP areas in this study could be sampled in <2 weeks by trained two-person field crews.

Timing and Cost of Surveys

There are two temporal scales to consider when designing a long-term monitoring program for vegetation. First, there are the temporal changes that occur within a growing season. We recommend that surveys be conducted during June-August, with areas in the northern part of Pennsylvania being sampled later in the summer. However, most importantly, each time a block is sampled it should be sampled within two weeks of the date it was sampled previously. This is because there are clear phenological changes

Table 33. Comparison of measures of precision for tree seedling stem densities (30–150 cm tall) under the sampling effort in 2006 and a hypothetical sampling design in which only 25% of blocks are sampled but 20 sample points are visited per block.

			2006 sampling effort			Proposed sampling effort		
DMAP No.	State Forest	Stems/acre	SE	CV	Block:plot variance ratio	SE	CV	Block:plot variance ratio
18	Moshannon	1,721	736	43	1.93	597	35	3.96
29	Susquehannock	3,500	2,250	64	0.57	1,776	51	1.13
44	Tioga	1,175	534	45	0.88	387	33	1.82
54	Elk	954	549	58	0.52	453	47	1.05
55	Bald Eagle	168	159	95	0.71	124	74	1.42
99	Tuscarora	678	626	92	2.29	540	80	4.57
266	Delaware	535	454	85	0.63	372	70	1.26
370	Loyalsock	1,063	552	52	0.49	434	41	0.98
543	Micheaux	321	278	87	0.88	246	77	1.75
704	Sproul	678	541	80	0.95	391	58	2.20
931	Gallitzin	682	397	58	0.48	316	46	0.96

throughout the summer in flower emergence. For example, we found that visits later in the summer were much more likely to detect the presence of flowers (see Table 3).

Second, there is the issue of how often (annually, biennially, etc.) should this survey be conducted. Because costs, management or research objectives, and logistical issues greatly affect the optimal choice for time intervals between samples we cannot provide firm guidelines based solely on the results of this study. However, there are some general issues to consider. A vegetation monitoring program at Valley Forge National Historical Park detected a response in vegetation in deer exclosures (relative to unfenced areas) after three years (D. R. Diefenbach and W. C. Vreeland, unpublished report, National Park Service, Eastern Region, Philadelphia, Pennsylvania). Thus, it may be possible to detect vegetation changes with large declines in deer abundance in 3-4 years.

To reduce the number of personnel required to conduct the surveys, a crew of two people could survey six to eight DMAP areas during June-August each year. Thus, a single crew could survey about 12 DMAP areas every two years or 18 areas every three years. Mahan et al. (2007) provide more discussion about sampling schedules for long-term vegetation monitoring programs. We estimate it would cost about $15,000–$20,000 each summer data are collected, which would include a two-person crew for about 800–1,000 hours and 5,000 vehicle miles. Additional expenses would involve database management and data analysis but likely could be performed by existing staff.

Metrics to Retain for Future Surveys

Many of the measurements we collected are likely to be useful and can be collected in a quick and efficient manner. Below we identify measurements we recommend retaining in this protocol.

Trees.–We recommend continuing to record basal area (prism plot) and dbh of trees (>10 cm dbh). These data are necessary for categorizing overstory stocking, which is important to assess light conditions that affect tree regeneration and other understory plants.

Saplings and shrubs.–The 1.5 m × 40 m plot used to estimate stem density of shrubs and tree saplings (>1.5 m tall and <10 cm dbh) provided reasonable precision of stems/acre (CV = 25–42%; Table 8). Stem densities can be used as part of an index to advanced regeneration (Table 30). Furthermore, plots with high densities (>1,000 stems/acre) of interference species should be excluded when assessing advanced regeneration.

Percent cover.–We recommend continued collection of percent cover of fern, *Rubus*, grass, and forbs (on 3.5-m radius plots). In particular, estimates of fern cover are the most important information because plots with >25% fern cover should be excluded when assessing advanced tree regeneration. The percent cover of other species or plant forms is simple to collect and cost little in terms of time or effort.

Tree seedlings.– We originally proposed collecting stem densities, by species, for seedlings 30–150 cm tall because seedlings >30 cm indicate deer browsing is not inhibiting regeneration. We recommend retaining this measure for two reasons. First, any increase in the number of stems >30 cm tall should be evident if data are collected every three years. Second, this information is an important component to calculating an index to advanced regeneration. The precision of estimates of stem density for seedlings was poor (CV = 43–95%; Table 11), but if changes over time are calculated as paired differences there may be greater power to detect changes.

Herbaceous species.–We recommend continuing to count numbers of plants of Indian cucumber and Canada mayflower, as well as the number of Canada mayflower that are flowering. Both of these species are widespread and relatively abundant. Percent of Canada mayflower plants flowering, although extremely low in this study, is supposed to be a good indicator of deer browsing intensity (Rooney 1997).

Measurements of the height of the tallest specimen of Indian cucumber should be continued because they are likely good indicators of deer browsing intensity. Descriptions of these species (e.g., http://plants.usda.gov) provide typical heights for each species. Even though we measured the tallest specimen, mean heights were near or below the range of typical plant heights (Figure 9). If this reduced height is an effect of deer browsing, then this measure potentially could be a sensitive indicator of deer browsing.

We strongly recommend that heights of Indian cucumber be measured in deer exclosures throughout the state. If the heights of plants when deer browsing is eliminated or extremely low are much greater than the heights measured in this study, then it is likely that reduced deer densities should result in a fairly rapid response in height of this species.

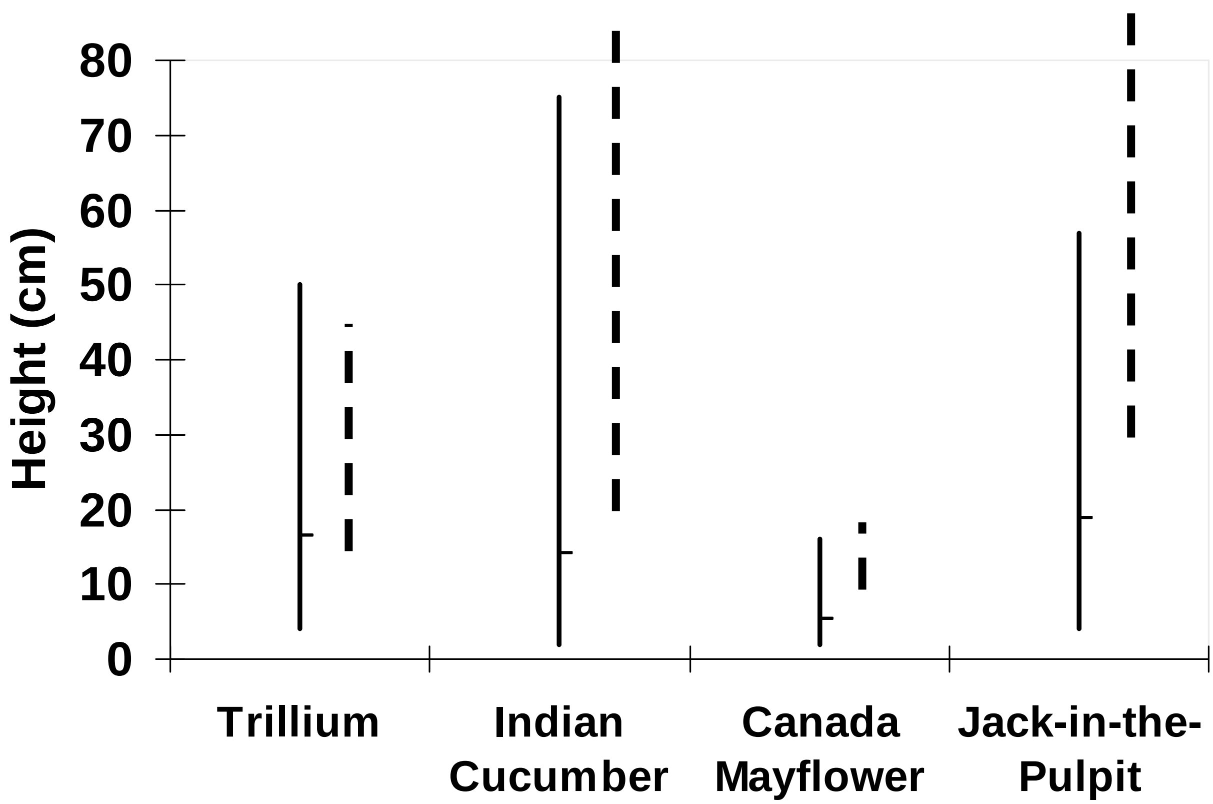

Figure 11. Mean, minimum, and maximum height measurements of the tallest specimen present on 1.5-m radius plots of four flower species along with the reported range of typical heights for each species (dashed lines).

Metrics to Exclude from Future Surveys

Recording whether each tree seedling (30–150 cm tall) had evidence of deer browsing was time consuming and likely subjective or prone to error (being missed by observers). Furthermore, changes in browsing could be caused by changes in food availability or tree species composition rather than changes in deer abundance. A tree species had to be present before it could be browsed, and browsing intensity is likely influenced by the presence of other species. Given that browsing of palatable and unpalatable species was similar (Table 32), and sometimes greater for unpalatable species, this suggests that understanding seedling spatial distribution and species composition is important to interpreting measures of browsing intensity. We recommend not collecting this information because it is unlikely to be readily interpreted.

Deer are known to prefer *Rubus*, but because this species does not tolerate shade it was rarely encountered during our sampling. Consequently, under the sampling design implemented in this study, *Rubus* is unlikely to be a reliable measure of deer browsing intensity. Similarly, we found viburnum shrubs, greenbriar, and elderberry to be relatively rare. Collecting this information on a presence-absence basis is simple to do, but elderberry is shade intolerant so is likely to remain rare even if deer browsing is affecting its abundance.

Hobblebush (a viburnum shrub) is highly preferred by deer but was only observed once during the study but outside of a sample plot. This species is likely rare because of deer browsing, but may lack the seed sources to respond even if deer browsing is eliminated.

Given that data on the percent cover of *Rubus* is easy to collect, we recommend retaining it in the sampling protocols, but do not anticipate it being a useful browse indicator. We recommend not collecting presence-absence data on elderberry. Viburnum shrubs and greenbriar were present on all but three of the study sites, so there may be the potential for these species to respond to reduced deer browsing.

Thompson and Sharpe (2005) reported greater variability in heights of trillium species explained by differences in edaphic conditions than by deer density as measured from pellet group densities. Rather than plant height, Rooney (1997) measured leaf length of Canada mayflower to assess whether deer browsing affected the size of plant. Consequently, given the acid soils found on most DCNR lands we do not believe height of trillium is likely to be a useful measure of deer browsing intensity. Furthermore, measuring leaf length of Canada mayflower is too time consuming. Finally, Jack-in-the-pulpit was not present on most study sites. We do not recommend collecting height information for these three species.

Implementing a Vegetation Monitoring Program

This study does not provide any direct information on the effects of deer browsing on current forest vegetation conditions. The data we collected simply provided estimates of various vegetation characteristics on the 11 DMAP areas selected for this study. Furthermore, we do not know by how much the measures that were chosen for this study will actually respond to changes in deer browsing as influenced by changes in deer density. For example, will percent of flowering Canada mayflower increase by 10% or 50% for a given reduction in deer density? In addition, there are a myriad of other factors that influence forest vegetation, including edaphic conditions, existing seed banks, silvicultural treatments (timber harvest, prescribed burns, fencing, etc.), and the temporal changes that occur as stands age (e.g., transition from pole to saw timber).

To further refine a vegetation monitoring program based on the recommendations presented in this report, changes in deer density are required during which repeated vegetation measurements are collected. We believe DCNR lands enrolled in DMAP are large enough for such an endeavor. However, there are some challenges.

First, such an undertaking requires a long-term perspective and commitment. For example, Valley Forge National Historical Park observed statistically significant changes in deer exclosures after three years. However, this was an extreme situation with deer densities exceeding 100 deer/mile^2 and exclosures containing zero deer, but even after 10 years only about 30% of deer exclosures contained sufficient tree regeneration to be considered adequately stocked. Consequently, it is quite possible that deer densities would have to be reduced for $\geq$10 years before statistically significant changes could be detected in forest vegetation on DMAP areas. Responses of forest herbs, however, might be detected sooner than increases in tree regeneration.

Second, monitoring changes in deer density is not easy because accurate estimates of deer populations are difficult to obtain and are usually expensive (Diefenbach and Vreeland 2005; http://pacfwru.cas.psu.edu/wildlife_compl.htm#FIG). Also, the proportion of hunters that report harvesting a deer is <1.0 (Rosenberry et al. 2004) and antlerless deer can be harvested on DMAP areas using either a special DMAP permit or regular antlerless license. This means that accurately monitoring the deer harvest on a DMAP area would necessitate changes in how hunters report the harvest of deer. Hunter harvest is the single greatest mortality factor for deer in Pennsylvania, and an accurate accounting of hunter harvest would allow stronger inferences about changes in deer densities.

Third, to quantify that deer are affecting the forest vegetation it may be necessary to install deer exclosures on the study area to make sure that reduced deer densities should result in a detectable change in vegetation and what type of changes to expect to occur. This is a concern because a lack of change observed in the vegetation monitoring component of the program could be from (a) no change in response to reduced deer densities, or (b) a failure to detect a statistically significant change, or (c) not measuring the appropriate vegetation characteristic. The use of deer exclosures could exclude the possibility that reducing deer densities has no effect on vegetation or that the wrong vegetation characteristic is being monitored.

Incorporating Vegetation Monitoring into Forest Restoration

The terms "forest restoration" and "fixing our forests" have been discussed frequently in Pennsylvania ever since Dr. Gary Alt began implementing changes in the Pennsylvania Game Commission's Deer Management Program to reduce deer abundance. However, what is it about our forests that needs to be restored or fixed? Is it the shift from oak to red maple? Is it clearcuts that fail to regenerate the forest? Is it the spread of invasive ferns? Is it the loss of understory herbs and other non-commercial vegetation? Does it extend to vertebrate and invertebrate animal communities? Is it the acidification of soils? Is it the changes due to lack of fire? Or is it just deer?

Research that has studied forest vegetation in the context of known densities of deer in an experimental framework has contributed enormously to our understanding of the effects of deer herbivory on forest conditions, especially with respect to tree regeneration (e.g., Horsley et al. 2003). However, this knowledge cannot be translated easily to a management context because of the many uncontrollable factors associated with managing deer and forests. Few published studies (<20%) have addressed the interaction of ungulate herbivory with other vegetation disturbances, and even fewer (<10%) have explicitly made inferences to landscapes as large as watersheds (Wisdom et al. 2006). Many characteristics of deer populations are only estimated, such as population density and number harvested. Moreover, the spatial distribution of deer on the landscape is not uniform. In turn, forest management also includes many uncertainties. Tree regeneration depends upon such factors as edaphic conditions, interspecific plant competition, climate, seed banks or seed crops, land use history, deer herbivory, and many others.

Despite all these uncertainties in the system, however, DCNR and PGC must make management decisions about deer populations and forest habitats on a recurring basis. For example, the PGC annually sets harvest regulations to manage the deer population and both DCNR and PGC must harvest timber and set objectives under their multi-year planning process. Thus, if we are going to learn how to manage deer so that we can also manage forest ecosystems on a sustainable basis we must be prepared to conduct research on the systems being managed within the context of existing management decision frameworks. Such an approach has been termed adaptive resource management (ARM, Walters 1986) and has been implemented in such natural resource disciplines as fisheries management (Smith et al. 1998) and waterfowl management (Williams and Johnson 1995), and was recommended for deer and forest ecosystem management in Pennsylvania by Latham et al. (2005).

The vegetation monitoring protocol proposed in this report would be fundamental to any attempt to perform forest restoration in a management-research (ARM) context. That is, management decisions would be accompanied by a monitoring program so that outcomes could be assessed in a quantitative, objective manner. As monitoring proceeds new data are collected to evaluate and help refine models as well as improve our understanding of how the ecosystem being managed functions.

Besides embracing uncertainty when making management decisions, the other advantage of ARM is that it can confront controversy in an objective and scientific manner (Williams 2003). Three primary factors have been espoused in the scientific literature, and touted in the popular press, as affecting the health of Pennsylvania's oak forests: acid deposition, lack of fire, and excessive deer herbivory. Oftentimes, the importance of any one of these factors has been promoted to the exclusion of all others. Thus, ARM provides an opportunity for scientists with different models to test their models' ability to predict the outcome of a management action. For example, one model (e.g., Marquis et al. 1992) may use existing stand conditions (advanced regeneration, interfering species, etc.) to predict the regeneration success of a forest stand at a given deer density. In contrast, other models might predict different outcomes based on edaphic conditions (Sharpe and Drohan 1999) or fire and land use history (Abrams 1992, 1998, 2003).

Making management decisions for deer populations and forests in a landscape context is filled with uncertainties that cannot wait for controlled experiment results. Horsley et al. (2003) conducted a 10-year experiment that studied the effects of deer herbivory (4 levels) in a single forest type. It is unlikely this experiment will be replicated in the near future, let alone in different forest types. Johnson (1999) noted, "If uncertainty is not critical for a particular management problem, or if it can be addressed with small-scale research, then traditional management approaches are probably appropriate. However, if uncertainty is critical and can only be addressed by manipulating the system(s), then I contend that adaptive management is the most useful approach currently available."

Proponents of the different hypotheses regarding the factors affecting forest regeneration have all recognized that multiple factors influence forest regeneration (e.g., Abrams 1992). In fact, Sharpe and Drohan (1999:199) noted that "To understand what is happening to Pennsylvania's forest regeneration, one must embrace the concepts of multiple environmental stresses acting simultaneously." In this context, deer management, forest vegetation monitoring, and land management decisions are all integrated along with a research component. This has been coined 'learning by doing' (Walters 1986).

Conclusions and Recommendations

1) In the sampling design, reduce the number of blocks visited and increase the number of sample points within each block. For DMAP areas of <20 square miles, we recommend visiting five blocks (sampling fraction $\geq$25%). For larger DMAP areas, visit an additional block for every additional 10 square miles of area above 20 square miles (sampling fraction $\geq$20% for 30 mi^2, $\geq$16% for 50 mi^2, etc.). Also, we recommend each block contain 20 sample points (instead of 10). These changes to the sampling design greatly reduce the number of blocks that need to be visited but results in equivalent precision of estimates.

2) We recommend retaining the following data collection in the protocols:
   - Tree (>10 cm dbh) basal area and dbh to be able to calculate overstory stocking and assess understory light conditions;
   - Stem density, by species, of shrubs and saplings >1.5 m tall and <10 cm dbh to assess advanced tree regeneration and identify sites with problems with interference vegetation;
   - Percent cover of *Rubus*, ferns, grasses, and forbs primarily to identify sites with >25% fern cover and potential tree regeneration problems;
   - Stem density of tree seedlings (30–150 cm tall), by species, to assess advanced tree regeneration;
   - Counts of Indian cucumber and Canada mayflower, and to record the number of flowering Canada mayflower; and
   - Height of the tallest Indian cucumber on each plot.

3) Under the proposed sampling protocols, the following forest vegetation indicators could be monitored:
   - Percent of plots adequately stocked with advanced tree regeneration on plots with <25% fern cover, <1,000 stems/acre of interference shrubs and saplings, and <75% overstory stocking;
   - Stem density of tree seedlings 30–150 cm tall, which could also account plots with interference vegetation and inadequate overstory conditions;
   - Counts of Indian cucumber and Canada mayflower;
   - Percent of Canada mayflower plants that are flowering; and
   - Height of Indian cucumber.

4) We strongly recommend that heights of Indian cucumber be measured in deer exclosures throughout the state. If the heights of plants when deer browsing is eliminated, or extremely low, are much greater than the heights measured in this study, then it is likely that reduced deer browsing should result in a fairly rapid response in height of this species. This information would also provide guidance in terms of what changes to anticipate and for establishing quantitative criteria to assess whether deer reductions have resulted in a change in vegetation.

5) Implementation of this monitoring protocol will require a long-term commitment to monitoring (>10 years) and preferably manipulation of deer densities to have

any chance of detecting vegetation responses to changes in deer browsing. Such an effort may require changes in how deer harvest is permitted and monitored so that accurate estimates of deer harvest are obtained. In addition, it may be necessary to employ deer exclosures to ensure that vegetation characteristics being measured are likely to respond to reduced deer densities.

6) The monitoring protocol proposed in this report would be a fundamental component of any attempt at “forest restoration.” In an adaptive resource management framework, forest management and deer population management decisions would be designed to understand how the system responds, and the vegetation monitoring protocol in this report could be used to provide feedback on ecosystem changes.

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