Deer Impacts on Vegetation in Ann Arbor Park Natural Areas

Summary of Monitoring Metrics for 2017

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NatureWrite LLC

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EXECUTIVE SUMMARY

Deer led to negative impacts on vegetation in Ann Arbor natural areas across all monitoring methods and metrics. Although results vary somewhat across sites and species, every metric shows negative effects of deer (Table 1); sites monitored are shown in Table 2.

Oak seedling metric: % seedlings deer browsed

- Deer browsed 65% of experimental red oak seedlings totaled across 13 City natural areas monitored, with browse levels of 50% or more at 10 of 13 sites. Deer browsing at all parks exceeds the 15% level beyond which oak forest regeneration is likely to fail.

- Highest deer browse levels were at White Oak (90%) and Furstenberg (84%); lowest browse levels were at Hansen (30%), Cedar Bend (32%), and Black Pond Woods (39%).

- Deer browsing on oaks increased somewhat in 5 of 8 natural areas where results can be compared from 2016 to 2017, and declined in 3 sites (Black Pond Woods, Mary Beth Doyle, and the Bird Road area in Bird Hills).

- Data do not show clear trends in response to deer management in 2016 and 2017.

Wildflower metrics: % deer browsed, % mortality, % flowering & fruiting

- Deer browsed 70% or more of experimental wildflower plants at 4 sites (Bird Hills, Black Pond Woods, Furstenberg, and Sugarbush) and 50% at the 5th (Mary Beth Doyle).

- Deer were linked to significantly higher % mortality of experimental wildflower plants across sites, with 15% fewer plants surviving in deer-accessible unfenced plots at 3 of the 5 sites.

- Deer were associated with lower % flowering at 4 of 5 sites, with flowering rates 13–27% lower in unfenced deer-accessible plots than fenced plots.

- % fruiting was lower in deer-accessible unfenced plots at all sites.

- Overall, deer halved the % flowering of big-leaved aster and bluestem goldenrod in unfenced plots compared to fenced plots.

Trillium exclosure study: Trillium abundance, flowering, and % change

- Deer reduced total trillium abundance and total trillium flowering of naturally occurring populations in unfenced deer-accessible plots compared to fenced (exclosure) plots from 2016 to 2017 in 4 of 5 sites (Arboretum, Bird Hills, Black Pond Woods, Lakewood).

- A 5th site (Mary Beth Doyle) did not show clear deer impacts.

- Deer-accessible unfenced plots had significant declines (change in # of plants and # flowers in 2017 as % of initial 2016 populations) relative to fenced plots where trillium populations were protected.

Change in vegetation impacts from 2016 to 2017

- Vegetation metrics do not yet show clear reductions in deer impacts, although it takes 3 years of data to fully establish trends, and data reported here show vegetation response to deer management in 2016 and 2017 but not yet 2018.

- Where complete data for 2016 and 2017 can be compared, deer browse levels on oak seedlings declined at 2 sites near 2017 deer management areas: Black Pond Woods (near Leslie Park Golf Course) and Bird Hills–Bird Road (although it increased at Bird Hills–Newport Road, for an overall increase of the combined total at Bird Hills).

    - Decreases in % oaks deer browsed were, however, still associated with increased % mortality and reduced % flowering and % fruiting of experimental wildflowers, and reduced trillium abundance and flowering, at both Bird Hills and Black Pond Woods.

This summary report presents general information about each study and focuses on results for the key metrics. An accompanying full report***, Deer Impacts on Vegetation in Ann Arbor Park Natural Areas: Complete Monitoring Methods and Results, 2016–17,*** provides greater detail about experimental methods and results for additional measurements, including breakdowns of wildflower results by site and species, and also provides complete references and citations for relevant scientific studies.

Table 1. Summary of metrics for deer impacts on vegetation, by site. For % oak seedlings deer browsed and % wildflowers deer browsed, higher numbers indicate more severe deer impacts. For the remaining metrics, lower (more negative) numbers show more severe deer impacts: data show the *difference* in plant performance between fenced plots where plants are protected from deer and adjacent deer-accessible unfenced plots. Metrics in brown are from the red oak experimental seedling study, those in purple are from the wildflower experimental study, and peach color indicates the trillium exclosure study. The % wildflower survival is the inverse of mortality—lower (more negative) survival indicates higher mortality.

	Metrics (higher=worse)		**Metrics (lower=worse)**				
Site	**% oak seedlings deer browsed**	**% wildflowers deer browsed**	**Wild-flower % survival**	**Wild-flower % flowering**	**Wild-flower % fruiting**	**Trillium % change, abun-dance**	**Trillium % change, flowering**
Arboretum, Nichols (UM)†	72%*					-64%	-12% (NS**)
Bird Hills	70%	70%	-18%	-27%	-20%	-44%	-8%
Black Pond Woods	39%	72%	-18%	-13%	-20%	-49%	-48%
Cedar Bend*	32%*						
Dhu Varren*	79%						
Furstenberg	89%	72%	-5%	0%	-7%		
Hansen	30%						
Huron Hills Golf Course	50%						
Huron Parkway*	79%						
Lakewood	50%					-42%	-60%
Leslie Woods*	90%						
Mary Beth Doyle	53%	50%	3%	-27%	-20%	-30% (NS**)	-19%
Oakwoods*/ Sugarbush	63%	70%	-15%	-20%	-13%		
White Oak	95%						

* Oak seedlings at these sites were planted May/June 2017 so have not yet been monitored for a full year; all others planted December 2016–January 2017. **NS = Difference Not Significant (p>0.05) using statistical tests of average plot data. Due to high variability between plots within the site, there is greater than a 5% probability that difference is due to random factors rather than treatment effects. †The study at Nichols Arboretum was separately contracted by the Matthaei Botanical Gardens/Nichols Arboretum (University of Michigan), which has agreed to share results for comparison here.

OVERVIEW

In 2015, the City of Ann Arbor began monitoring deer impacts on vegetation, contracting with Dr. Jacqueline Courteau/NatureWrite LLC to assess deer browse in 10 city park natural areas using experimental red oak seedlings ("sentinel seedlings") to provide a standardized measure of deer impacts across parks. Results from the initial year of monitoring (November 2015–January 2017) were reported previously.

The City contracted with NatureWrite LLC to expand monitoring in 2016–17, adding sites and monitoring methods to incorporate three separate but related studies:

- **Red oak experimental seedlings** in 9 of the 10 City parks/natural areas previously monitored plus 4 new City natural areas, along with University of Michigan's Nichols Arboretum,[1] for a total of 14 different natural areas. Bird Hills is large, so seedlings were planted in 2 different sites. In all, results are reported for 15 planting sites.
- **Wildflower experimental plantings**, in 5 natural areas.
- **Trillium exclosure study**, focused on trillium in 5 natural areas: 4 City natural areas plus a separate study at Nichols Arboretum.[1]

Study locations are shown in Figure 1. This report presents summary results for key metrics from these three studies, covering over 2,000 individual plants.

- **Red oak experimental seedlings, % oak seedlings deer browsed**: 300 seedlings were planted and monitored for deer browse in 13 city park natural areas (plus Nichols Arboretum). At 8 areas, seedlings have been monitored for a full 12 months, but at 5 areas, seedlings have been in place for just 10 months—these sites will be monitored again at the end of 12 months and results updated if necessary.
- **Wildflower experimental plantings, % wildflowers deer browsed, % mortality (or survival), % flowering and % fruiting:** 650 wildflower stems of 7 species were transplanted into fenced and unfenced plots and monitored throughout the 2017 growing season. Prolonged dry weather inhibited growth and flowering, but all metrics are reported for different species as appropriate.
- **Trillium exclosure study, total trillium abundance and flowering, and % change from 2016 to 2017 in unfenced relative to fenced plots:** data are presented on abundance and flowering of over 1,075 trillium plants after one full year of protection from deer compared to plants left open to deer (half of the plots were fenced *exclosures* that prevent deer access).

This report presents data for each monitoring component separately, then compares different monitoring measurements across sites where multiple studies were done. Taken together, the three studies provide insight on deer impacts on specific tree and wildflower species, as well as on community processes (such as forest regeneration) and on trophic webs (including provision of resources for pollinators and birds).

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[1] The University of Michigan Matthaei Botanical Gardens/Nichols Arboretum contracted separately with NatureWrite LLC for oak and trillium studies, and has agreed to allow results to be reported here for comparison.

VEGETATION STUDY LOCATIONS

Studies were placed in 14 Ann Arbor City park natural areas and, under a separate contract, University of Michigan's Nichols Arboretum (Figure 1, Table 2).

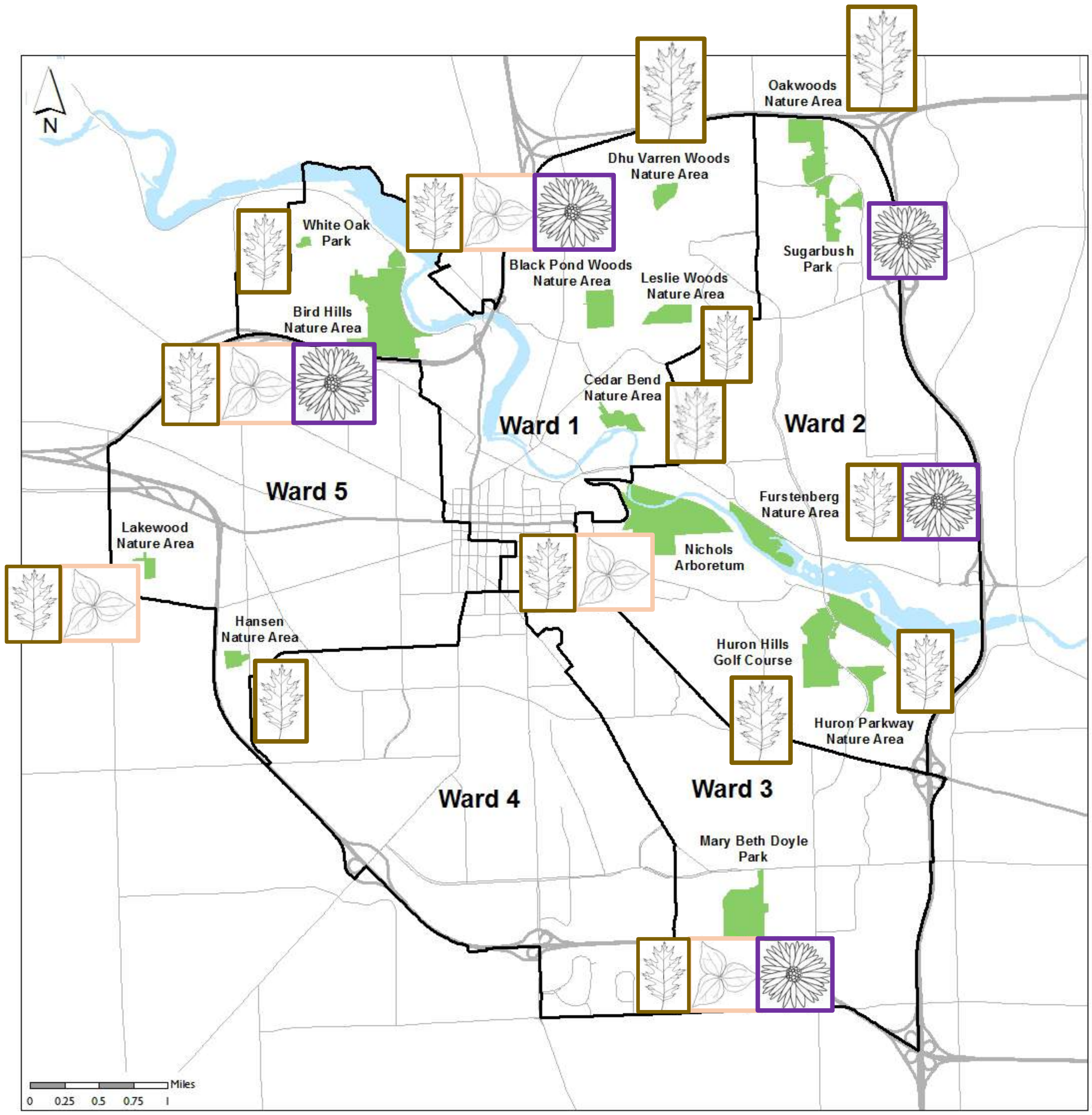

Figure 1. Study locations in Ann Arbor natural areas. Symbols show the different studies:

Red oak
experimental seedlings

Trillium
exclosure study

Wildflower
experimental plantings

Table 2. Overview of Ann Arbor natural areas where vegetation was monitored for deer impacts. Monitoring included a ***red oak experimental seedling study*** (conducted in 2015–16 and again in 2016–17), an ***experimental wildflower study***, in which stems of 7 perennial wildflower species were transplanted into fenced vs. unfenced plots and tracked for % mortality, % flowering, and % fruiting (2017), and a ***trillium exclosure study*** (comparing abundance and flowering over time of existing population in fenced exclosures vs. unfenced plots, 2016–17). Studies were placed 14 Ann Arbor City natural areas, as well as University of Michigan's Nichols Arboretum (†contracted separately by Matthaei Botanical Gardens/Nichols Arboretum, which agreed to share results for comparison). Bird Hills Nature Area is large enough (166 acres) so that it had two different study locations for the oak study—Bird Road and Newport Road—but trillium and wildflower plots were placed throughout, so oak results from the Bird and Newport Road areas are combined for comparing to trillium and wildflower data. Oakwoods Nature Area and Sugarbush Park, separated only by Green Road, each hosted only one study (oaks in Oakwoods and wildflowers in Sugarbush), but are paired for comparison of oak and wildflower results.




Site	Oak (2016)	Oak (2017)	Wildflower (2017)	Trillium (2016–17)
Arboretum, Nichols (Univ. of Michigan)†	X	X		X
Bird Hills Nature Area (2 sites for oak study, Bird Road & Newport Road)	X	X	X	X
Black Pond Woods Nature Area	X	X	X	X
Cedar Bend Nature Area		X		
Dhu Varren Nature Area		X		
Furstenberg Nature Area	X	X	X	
Hansen Nature Area	X	X		
Huron Hills Golf Course (Woods)	X	X		
Huron Parkway Nature Area	X	X		
Lakewood Nature Area	X	X		X
Leslie Woods Nature Area		X		
Mary Beth Doyle Park	X	X	X	X
Oakwoods Nature Area/Sugarbush Park		X	X	
White Oak Park	X	X		

Sites were selected with several criteria:

- to encompass a range of large and smaller natural areas, including those with high-quality plant communities (such as Bird Hills, Mary Beth Doyle, Black Pond Woods);
- to represent areas found in aerial surveys to have higher and lower deer densities;
- to achieve geographical coverage of the city.

The red oak experimental seedling study was expanded from 2016 to include more sites in 2017. The trillium study was conducted in natural areas larger than 5 acres with notable trillium populations. Three sites had all three studies, so that results of the different study methods could be compared.

RED OAK EXPERIMENTAL SEEDLINGS

% OAK SEEDLINGS DEER BROWSED

A total of 65% of seedlings were browsed by deer, with browse levels of 50% or higher in 12 of 15 planting sites.

Red oak seedlings were browsed at rates ranging from 30% at Hansen to 89% at Furstenberg and 95% at White Oak over the course of a year (Figure 2). Over half the sites had deer browse levels greater than 60%. Among the five natural areas where seedlings have been in place for less than a year (indicated with an * on Figure 2), Dhu Varren, Huron Parkway, and Leslie Woods have deer browse levels of more than 60% in less than a full year of monitoring.

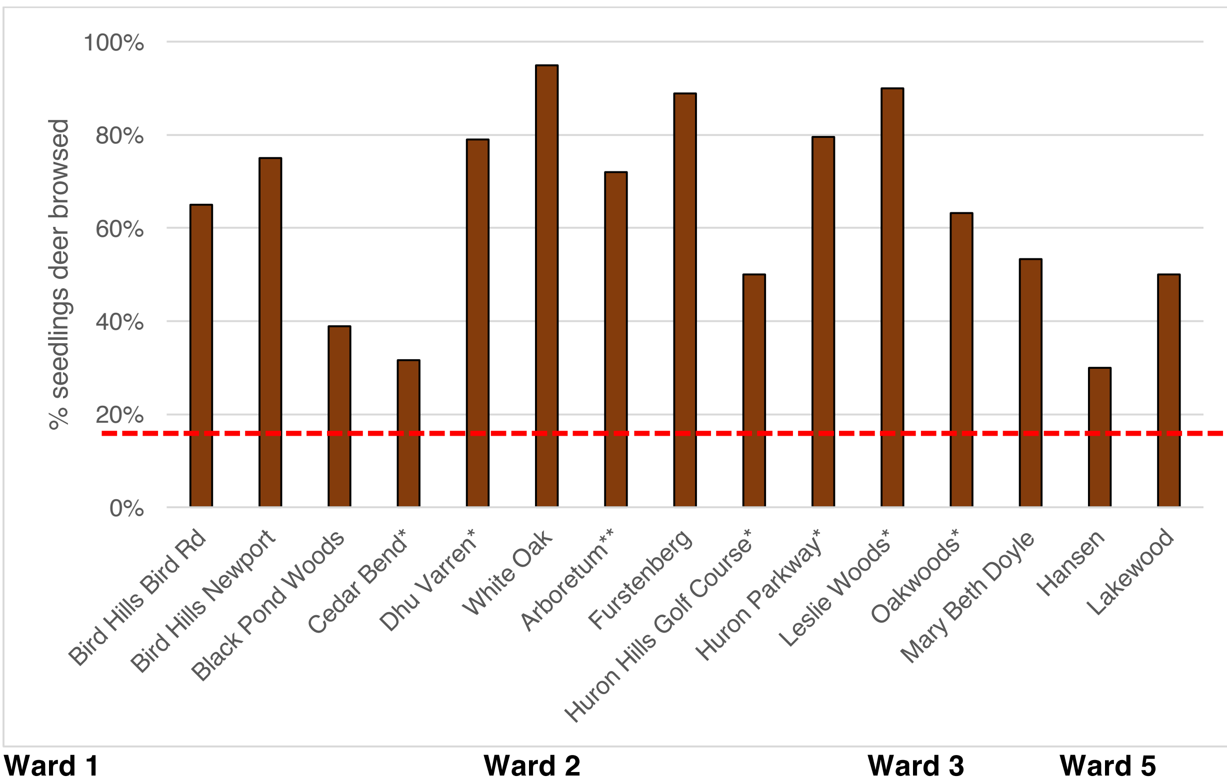

Figure 2. % oak seedlings deer browsed in Ann Arbor parks/natural areas. The dotted red line indicates the 15% annual browse level above which oak forest regeneration is unlikely to succeed (Blossey 2014, citation p. 8). * Seedlings were planted in May 2017 so they have not yet been in place and monitored for a full year at nature areas marked with an asterisk. ** Seedling plots at the Arboretum were vandalized and many seedlings lost or destroyed before final 2017 data could be recorded, so the browse % is likely an underestimate.

Hansen had the lowest browse levels, despite observations of browse damage elsewhere in the site. Wildflowers in an adjacent old field were heavily browsed, and may be serving as a primary food source for deer in this natural area. Cedar Bend has not yet been monitored for a full year, but had the second lowest browse levels.

Black Pond Woods and Mary Beth Doyle, which also had browse levels less than 50%, host other monitoring studies (experimental wildflower plantings and trillium exclosures), so browsing on oaks can be compared to impacts on other species, below. In both sites, we routinely observed deer during the daytime in and near our plots as we worked, and we noted browse damage on numerous herbaceous plants adjacent to unbrowsed red oak seedlings.

The proportion of oak seedlings that are browsed each year is a key indicator of oak forest regeneration impacts. As noted by Blossey (2014)[2], oak regeneration is likely to decline when more than 15% of seedlings in a given site are browsed per year:

> An individual oak seedling may need 10–20 years to grow out of reach of a deer under a forest canopy, and even longer to get into the canopy. In many instances, seedlings/saplings need to spend extended periods in the understory waiting for their chance to grow should the overstory be damaged (or harvested). Considering this early life history, more than an occasional browsing event on oak sentinels (damage to >3 of 20 [15%] seedlings) in any given year would indicate deer populations in the area are too high to achieve forest regeneration.[2]

Oak seedlings may be a conservative gauge of deer browse damage on the full suite of forest species. As noted in the Blossey (2014) report,

> …[M]ore preferred and browse-sensitive species, such as red and white trilliums (*Trillium erectum* and *Trillium grandiflorum*, respectively…), are severely browsed even in places where we see good survival of oak seedlings.[2]

The fact that we routinely observed deer browse damage on herbaceous plants adjacent to unbrowsed oak seedlings suggests that this may be the case in Ann Arbor sites as well. Data on wildflower species, presented below (p. 9), can be compared to browse on oaks to gauge how well oaks are indicating impacts to other species (p. 21).

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[2] JR Boulanger, PD Curtis, and B Blossey, 2014. *An Integrated Approach for Managing White-Tailed Deer in Suburban Environments: The Cornell University Study.* Cornell University Cooperative Extension and the Northeast Wildlife Damage Research and Outreach Cooperative. 34 pp. Accessed online: http://wildlifecontrol.info/deer/Documents/IDRM_12-5-2014.pdf. Complete citations for additional references are available in the full report.

WILDFLOWER EXPERIMENTAL PLANTINGS

To complement experimental red oak seedlings as a standardized gauge of deer browse intensity, and to assess how damage on red oaks correlates with damage on wildflower species that provide important resources for native pollinators, songbirds, and other forest wildlife, we set up an array of experimental plantings using forest wildflower and flowering shrub species. This experimental approach, variously referred to in research literature as a “phytometer” or “bio-assay,” is similar to the red oak “sentinel seedling” approach, using a standard set of species transplanted into plots and tracked over time.

For this pilot year of the wildflower planting, we selected a range of forest flowering and fruiting species including spring flora, summer wildflowers, and a forest shrub that are valuable for pollinators. Available literature suggests that the species selected had differing levels of deer browse preference and value for pollinators (Table 3). We chose species that could serve as indicators of deer impacts on ecological communities and processes, including pollination and food webs. Species selection was also affected by availability of local-genotype nursery-grown plants in sufficient quantity and reasonable price for use in an experimental protocol that called for planting multiple individuals in 5 paired plots in each of 5 sites. After exploring numerous options, we selected and planted 7 species to ensure having at least 4 species that would survive (Table 3):

- **Spring flora**: Trillium (*Trillium grandiflorum*), Canada anemone (*Anemone canadensis*)

- **Summer wildflowers** with moderate to high pollinator value: big-leaved aster (*Eurybia macrophylla);* bluestem goldenrod, (*Solidago caesia)*; stiff goldenrod, (*Solidago rigida)*; Culver’s root (*Veronicastrum virginicum*)

- **Flowering/fruiting shrub**: red elderberry (*Sambucus racemosa*)

This study focused on compiling 4 metrics of deer impacts on wildflowers:

- **% wildflower plants deer browsed**
- **% mortality (or reduced % survival)**
- **% flowering**
- **% fruiting**

Additional data, including results by species and by site, as well as flowering tallies of naturally occurring wildflower populations in fenced vs. unfenced plots, are presented in the full report.

Table 3. Species, deer preferences, and pollinator values for wildflower experimental plantings in Ann Arbor, 2017.

Common name	Genus, species	Deer preference/ *Pollinator value*	Sources	Notes
Anemone, Canada	*Anemone canadensis*	No data—likely low preference/ *Medium*	1, 5,11	No data for this species, but other species in the genus (wood anemone [*Anemone quinquefolia],* and Japanese anemone *[Anemone X hybrid])* are rated as rarely damaged.
Aster, big-leaved	*Eurybia macrophylla*	Preferred/ *Medium*	5, 6, 9	Comprised an estimated 2–11% of deer diet in different Upper Peninsula Michigan sites during June–August.
Culver's root	*Veronicastrum virginicum*	Preferred/*High*	3, 4, 7, 8, 9	Obligate larval food for State Special Concern species, Culver's root borer moth (*Papaipema sciata)*, last recorded in Washtenaw County in 2008; also supplies nectar for many butterfly species, including skippers.
Elderberry, red	*Sambucus racemosa*	Preferred/ *Medium*	5, 11	*Sambucus canadensis* may be more highly preferred (some researchers refer to it as "deer candy") but was not available at native plant nurseries in the numbers needed.
Goldenrod, bluestem	*Solidago caesia*	Preferred/*High*	5, 9	Noted as preferred in publications, but abundant in Ann Arbor natural areas; observations suggest that it is less frequently browsed locally than other goldenrods, such as zig-zag goldenrod (*S. flexicaulis)*.
Goldenrod, stiff	*Solidago rigida*	Moderate-Preferred/*High*	2, 9	Flowering stems (but rarely basal rosettes) browsed in some sites but not others; may depend on other species available.
Trillium, common	*Trillium grandiflorum*	Preferred/ *Preferred*	5, 10, 11	Most studies find clear deer browse preference and impacts; preferred pollinator species in New England.

Sources: 1) Burroughs, Jordan P., and Thomas.A.Dudek. *Deer-Resistant Plants for Homeowners*. MSU Extension Bulletin E-3042, July 2008. http://www.ipm.msu.edu/uploads/files/deer_resistant_plants.pdf. 2) Courteau, J.B. *Deer impacts on vegetation and communities in the Leonard Preserve, Manchester, MI, 2014*. Report prepared for Washtenaw County Parks and Recreation Commission, September 2015. 3) Michigan Natural Features Inventory. *Papaipema sciata*, culver's root borer. https://mnfi.anr.msu.edu/abstracts/zoology/Papaipema_sciata.pdf. 4) Penn State College of Agricultural Sciences, Cooperative Extension, Pennsylvania Pollinator Series, http://ento.psu.edu/publications/pollinatorfood. 5) Rawinski, Thomas, *White-tailed Deer in Northeastern Forests: Understanding and Assessing Impacts*, NA–IN–02–14. U.S. Department of Agriculture/U.S. Forest Service. 2014, reprinted January 2016. www.na.fs.fed.us. 6) Rogers, Lynn L.; Mooty, Jack J.; Dawson, Deanna. *Foods of white-tailed deer in the Upper Great Lakes Region—a review*. General Technical Report NC-65. St. Paul, MN: U.S. Dept. of Agriculture, Forest Service North Central Forest Experiment Station. 1981. https://www.fs.usda.gov/treesearch/pubs/10129. 7) Wild Native Type Nursery, Butterfly Plants. www.wildtype.com. 8) Anderson, R. C., D. Nelson, M. R. Anderson, and M. Rickey. 2006. White-tailed deer (*Odocoileus virginianus* Zimmermann) browsing effects on quality of tallgrass prairie community forbs, pp. 63–68. In D. Egan and J. Harrington [eds.], *Proceedings of the 19th North American Prairie Conference*. University of Wisconsin-Madison, Madison, WI. 9) NRCS, *Pollinator-Friendly Plants for the Northeast U.S.* https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs144p2_027028.pdf. 10) Darling, E., & Barrett, S. 2011. Sit-and-wait pollination in the spring flowering woodland plant, *Trillium grandiflorum*. Journal of Pollination Ecology 5(11): 81–5. 11) Pollinator Partnership, *Selecting Plants for Pollinators, http://pollinator.org/PDFs/Guides /EBFContinentalrx13FINAL.pdf* and *http://pollinator.org/PDFs/Adirondack.rx2.pdf.*

WILDFLOWERS, % DEER BROWSED, BY SITE

Deer browsed 50% or more of experimental wildflower plants across all 5 sites, and 70% or more of plants at 4 sites.

Deer browsed more than 50% of wildflower experimental plantings in unfenced plots across all Ann Arbor park natural areas (Figure 3), totaled across 6 species.[3] Deer browsed 70% or more of the plants in 4 of 5 sites. This high level of browsing was surprising because many plants wilted and grew poorly during the dry weather. Deer typically browse plants from 6 inches (15 centimeters) to 6 feet (2 meters) tall, but few experimental plants attained heights as tall as 6 inches. Deer pushed at fence edges to browse several plants ***within*** fenced plots, but this analysis focuses on unfenced plots only; browsing on fenced plants is ***not*** included. Small mammals damaged few plants overall, significantly fewer than deer. Most plots had 0 to 4% of plants damaged by small mammals, but one plot had 8% small mammal damage.

Deer browse on wildflowers can affect occurrence and amount of flowering and fruiting—and the provision of resources for pollinators and other wildlife—within 1 to 2 growing seasons, in contrast to deer impacts on oak regeneration, which occur over a longer time.

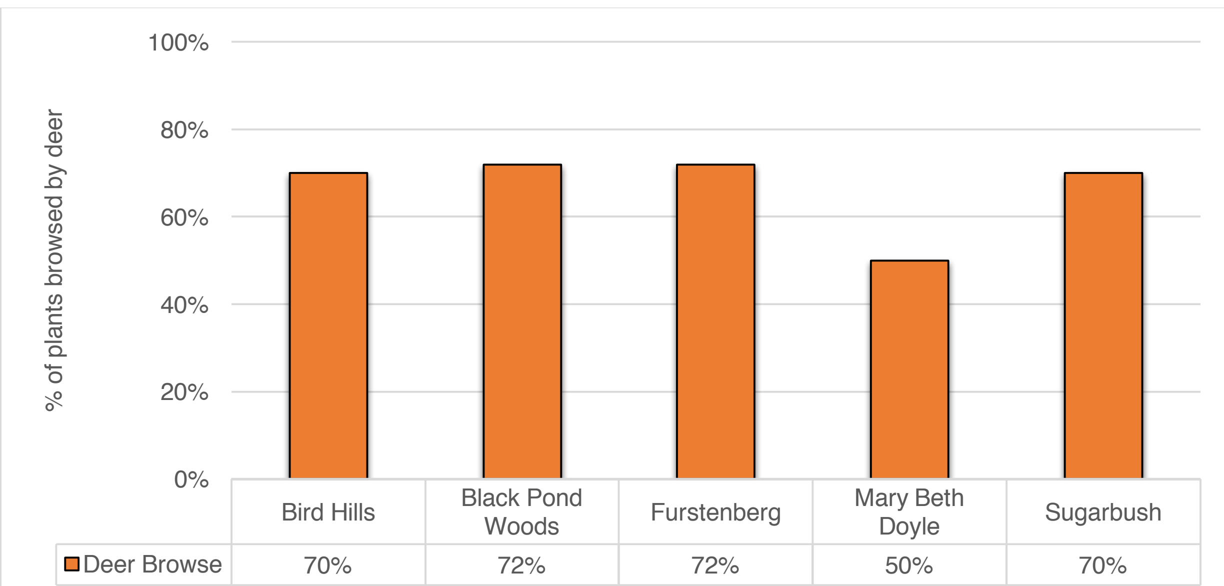

Figure 3. Deer browse levels on unfenced experimental wildflower plantings by site, 2017. Browse levels on 6 wildflower species are totaled across unfenced deer-accessible plots in 5 Ann Arbor natural areas. Deer browsing was highly significant overall (general linear model in R using site, plot, and species as factors, with sample size of 5 plots, yielded $p<0.0001$ for deer effects overall, indicating a less that 1/10 of 1% chance that this result could have been due to chance).

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[3] This analysis excludes trillium, which died back soon after planting, so deer browse could not be assessed.

WILDFLOWERS, % DEER BROWSED, BY SPECIES

Deer browsed 40% or more of stems of all species that could be assessed, with highest browse levels on red elderberry (100%) and big-leaved aster (86%).

Summed across all sites, deer browsed 50% or more of stems of all species except Culver's root. Deer were significantly more likely to browse red elderberry and big-leaved aster than other species; these two species were consistently browsed at high rates across all Ann Arbor sites. The strong preference for red elderberry supports findings from other studies that this species is highly preferred by deer (Table 3, p. 10). Big-leaved aster has also been noted as deer-preferred, and has been documented to be a notable summer food source for deer in Upper Peninsula sites (Table 3).

Deer browse levels on species other than aster and elderberry showed considerable variation across sites, suggesting that deer preferences can be highly localized and site-specific. For example, deer browsed only 30% of Canada anemone stems at Bird Hills, but 90% at Black Pond Woods. Bluestem goldenrod was the third most browsed species at Bird Hills (after elderberry and aster), with 80% of stems browsed there, but was a distant 4th choice at Mary Beth Doyle, where 40% of its stems were browsed. See full report for further results for individual sites and species.

The variability of deer browse preferences across sites supports the use of a suite of wildflower species for future studies. No single species is likely to be an ideal indicator across all sites in Ann Arbor. Data gathered from future years will help to clarify trends.

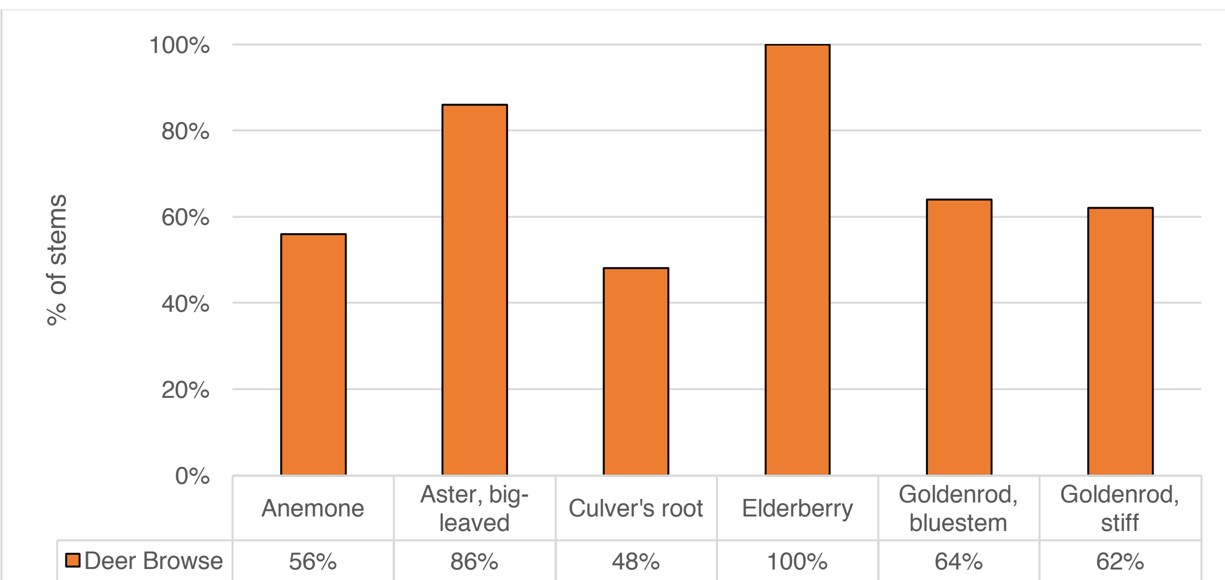


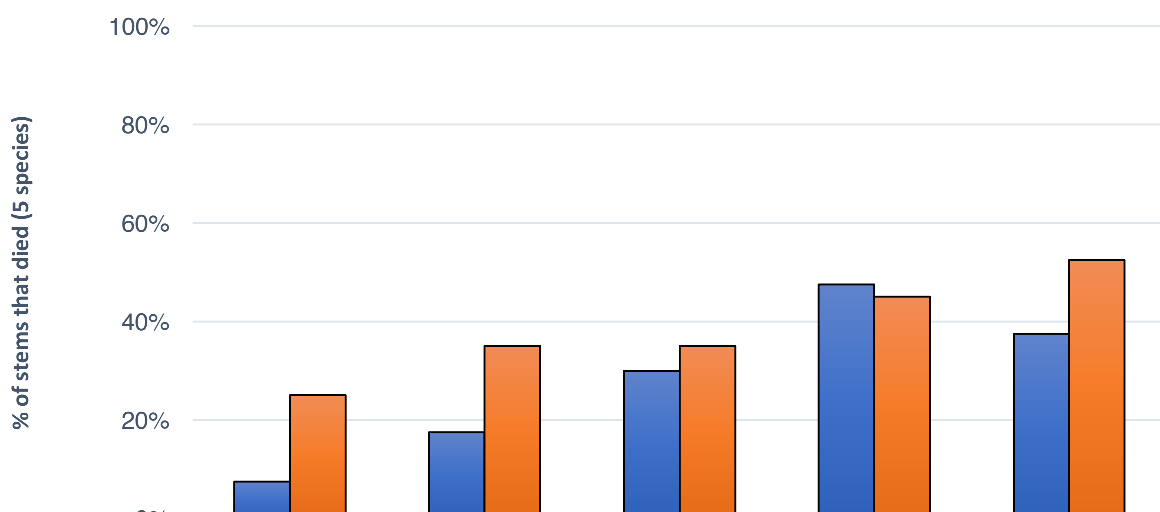
Figure 4. Deer browse levels on unfenced experimental wildflower plantings by species, 2017. Deer browse is totaled for unfenced deer-accessible plots across 5 Ann Arbor parks. Statistical analysis (general linear model in R using site, plot, and species as factors) shows that red elderberry (p=0.0002) and big-leaved aster (p=0.002) were significantly more likely to be browsed than other species overall. Deer browse could not be assessed on trillium, because most plants died back shortly after transplanting.

WILDFLOWERS, % MORTALITY

Deer presence was linked to significantly higher total wildflower mortality overall, with higher mortality of unfenced plants at 4 of 5 sites.

Total mortality rates for unfenced wildflower plantings accessible to deer were higher than for fenced plants protected from deer at every site except Mary Beth Doyle (Figure 5). Deer impacts on mortality are shown by the differences between plants in fenced plots, which represent the background mortality rates—including drought impacts—and those in unfenced deer-accessible plots. Despite considerable variation in mortality by species and site, deer impacts were still statistically significant overall, with mortality levels up to 3 times higher in deer-accessible unfenced plots than in fenced plots.

The slightly lower mortality of unfenced compared to fenced plants at Mary Beth Doyle is small enough that it cannot be distinguished from random variability using either the full statistical model or a simplified site-specific model.

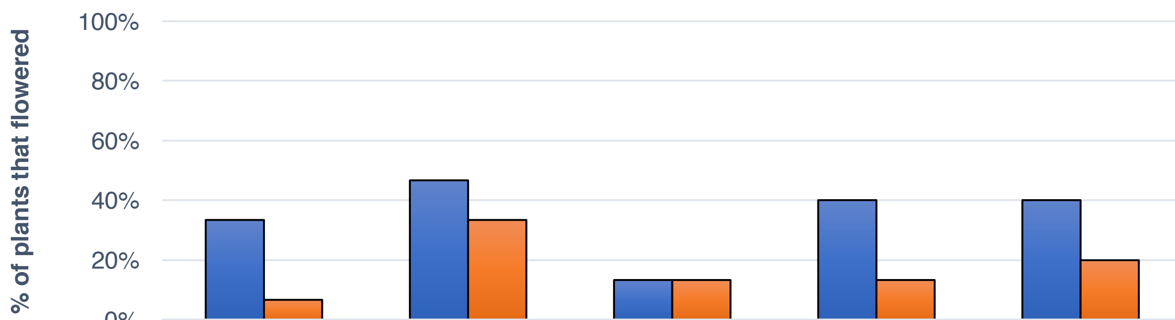


	Bird Hills	Black Pond Woods	Furstenberg	Mary Beth Doyle	Sugarbush
FENCED	8%	18%	30%	48%	38%
UNFENCED	25%	35%	35%	45%	53%

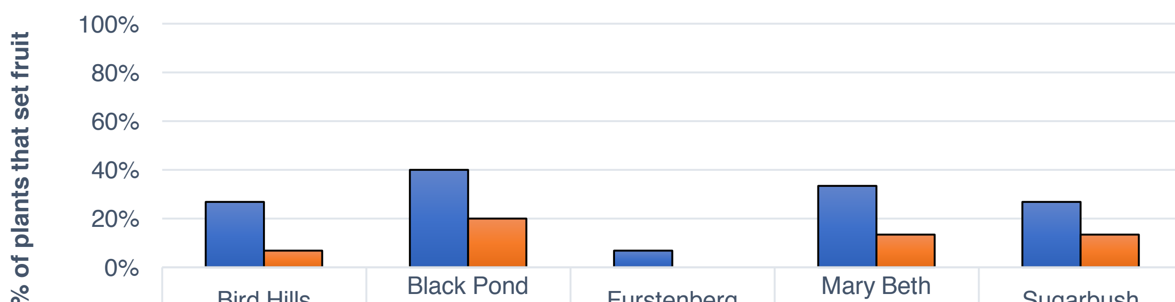
Figure 5. Mortality of experimental wildflower plantings by site, 2017. Mortality totals are shown for 5 species in fenced plots vs. unfenced deer-accessible plots at 5 Ann Arbor natural areas**.** Mortality was significantly higher overall for unfenced plants than for fenced plants, even considering significant differences in mortality across sites (general linear model in R with fencing, site, and species as factors; higher mortality for unfenced plants is significant at $p<0.01$ level, indicating a less than 1% probability that the difference was due to natural variability or random chance rather than experimental treatment). Mortality was significantly higher at Furstenberg, Mary Beth Doyle, and Sugarbush than at Bird Hills and Black Pond. The slightly higher mortality for fenced than unfenced plants at Mary Beth Doyle is not significant in the full model or in a simplified test (paired, 1-tailed t-test in Excel yielded $p=0.81$, indicating an 81% probability that the difference was due to chance or natural variability, rather than deer fencing treatment).

WILDFLOWERS, % FLOWERING AND % FRUITING

Deer significantly reduced % flowering and % fruiting of wildflowers overall.
Deer significantly reduced the total % of plants flowering and % fruiting summed across the two species that bloomed during the 2017 experiment (Figure 6), big-leaved aster and bluestem goldenrod. At 3 sites, flowering rates in deer-accessible plots were half or less the rates in fenced plots. Impacts differed somewhat by species (see full monitoring report for further details); however, because these species share a number of pollinators and bloom during the same time, the combined total indicates floral resources available for their shared pollinators, including bees, butterflies, and beetles.



	Bird Hills	Black Pond Woods	Furstenberg*	Mary Beth Doyle	Sugarbush
Fenced	33%	47%	13%	40%	40%
Unfenced	7%	33%	13%	13%	20%



	Bird Hills	Black Pond Woods	Furstenberg	Mary Beth Doyle	Sugarbush
Fenced	27%	40%	7%	33%	27%
Unfenced	7%	20%	0%	13%	13%

Figure 6. Proportion of wildflower plants that flowered and fruited by site, 2017. Totals are given for the two species (big-leaved aster and bluestem goldenrod) that flowered (above) and fruited (below) in fenced deer exclosures vs. unfenced deer-accessible plots at 5 Ann Arbor parks. Since only two species flowered and fruited, low sample sizes prevented clear findings from the full logistic regression model, but a simplified comparison of totals across sites shows that deer presence was linked with significantly reduced flowering and fruiting (1-tailed t-test with unequal variance comparing totals for fenced vs. unfenced plots across sites, p=0.02 for flowering and fruiting, indicating a 2% probability that results were due to natural variability or chance). At Furstenberg, where flowering rates were the same for unfenced and fenced plants, deer browsed flowering stems in unfenced plots soon after they were observed, so none set fruit.

TRILLIUM EXCLOSURE STUDY

While experimental plantings allow for standardized measurements across sites (plants of the same species, age, initial condition, etc.), assessments of existing plant populations using paired fenced and unfenced plots allow for a broader view of how plant populations recover with protection from deer in comparison to plants undergoing continued impacts. Furthermore, many spring wildflowers are long-lived perennials that may take several seasons to establish in experimental plantings, so studying plants already in place offers more timely information on flowering and fruiting.

To assess deer impacts on spring flora, we established paired fenced (exclosure) and unfenced plots in natural areas in four parks during May 2016: Bird Hills; Black Pond Woods; Lakewood; and Mary Beth Doyle. A similar study, contracted and separately paid for by the University of Michigan Matthaei Botanical Gardens/Nichols Arboretum was set up in Nichols Arboretum, offering a fifth site for comparison.

Evidence of deer browse on tender herbaceous plants, such as trillium, can be difficult to observe and document, as illustrated in photos of a trillium plot in Nichols Arboretum, below. Browsed stems wilt and disappear within a couple of weeks of being browsed, in contrast to woody stems, which show identifiable signs of deer browse for two or more years. However, counts of plant abundance and flowering in fenced vs. unfenced plots can show deer impacts even without definitive counts of deer browsed stems.

Browsed trillium stems, Nichols Arboretum, May 2016. Photo on left shows browsed stems of trillium in unfenced one-square-meter (10.8-square-foot) plot. Even with aluminum foil capping stems to make them more visible, it is challenging to find browsed stems. Photo on right shows the same plot, with each browsed stem circled. The plot contains 12 unbrowsed trillium stems with the characteristic 3 leaves, along with 27 stems that have been browsed by deer (leaves are removed and only stem remains). Also present are 9 stems of false spikenard or starry false-Solomon seal (*Maianthemum racemosum* or *M. stellata*). Photos: J B Courteau.

TRILLIUM ABUNDANCE AND FLOWERING

Deer were linked to significant decreases in trillium abundance in 4 sites. Overall, total trillium populations decreased from 2016 to 2017 in unfenced deer-accessible plots in four sites, but increased in fenced plots where they were protected from deer (Figure 7). Nichols Arboretum (Arb) had both the largest increase in the trillium abundance in plots protected from deer, and the largest decline in abundance where deer were present. Among city park sites, Black Pond Woods had the largest increase in trillium abundance in fenced plots, while Lakewood had the largest decline. (Trillium populations at the 5th site, Mary Beth Doyle, were an order of magnitude larger than other parks at the outset, and are discussed below, on p. 19.)

Although trillium populations can vary in size from year to year due to weather or other environmental stresses, the comparison of fenced vs. unfenced plots suggests that differences were due to deer rather than general inter-annual variation.

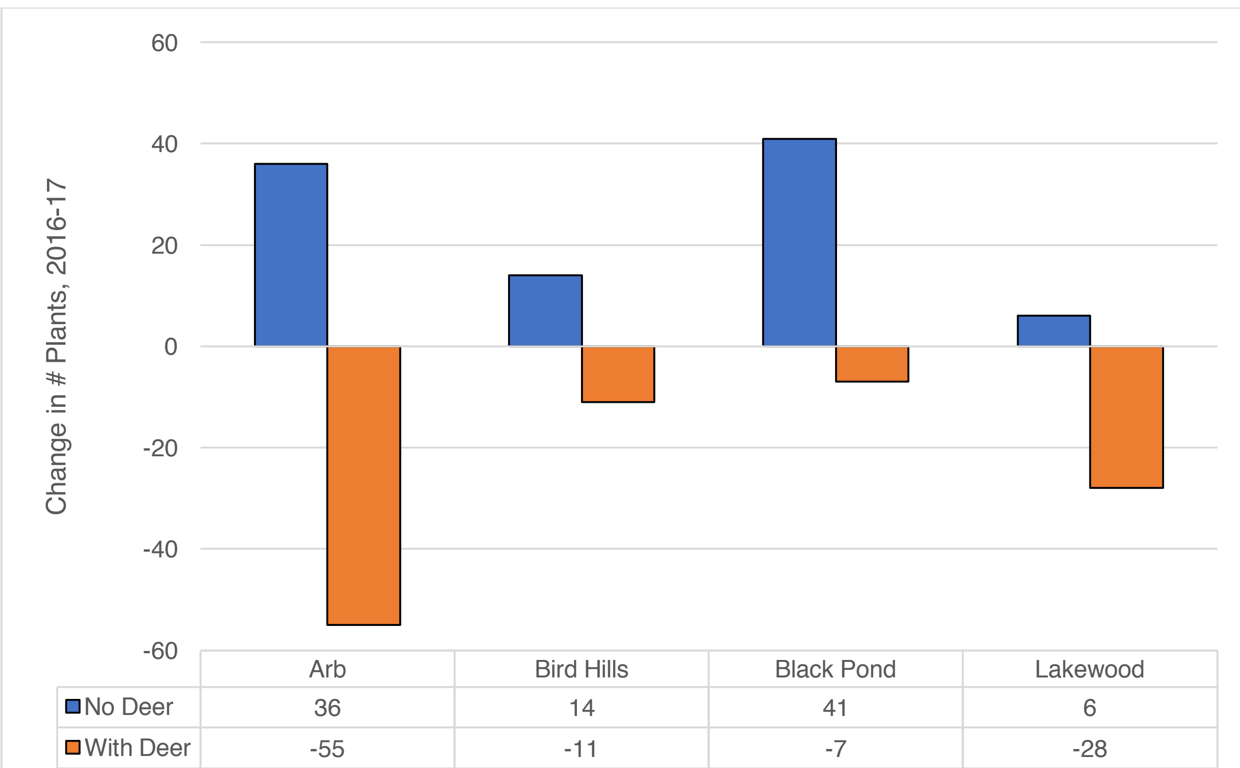
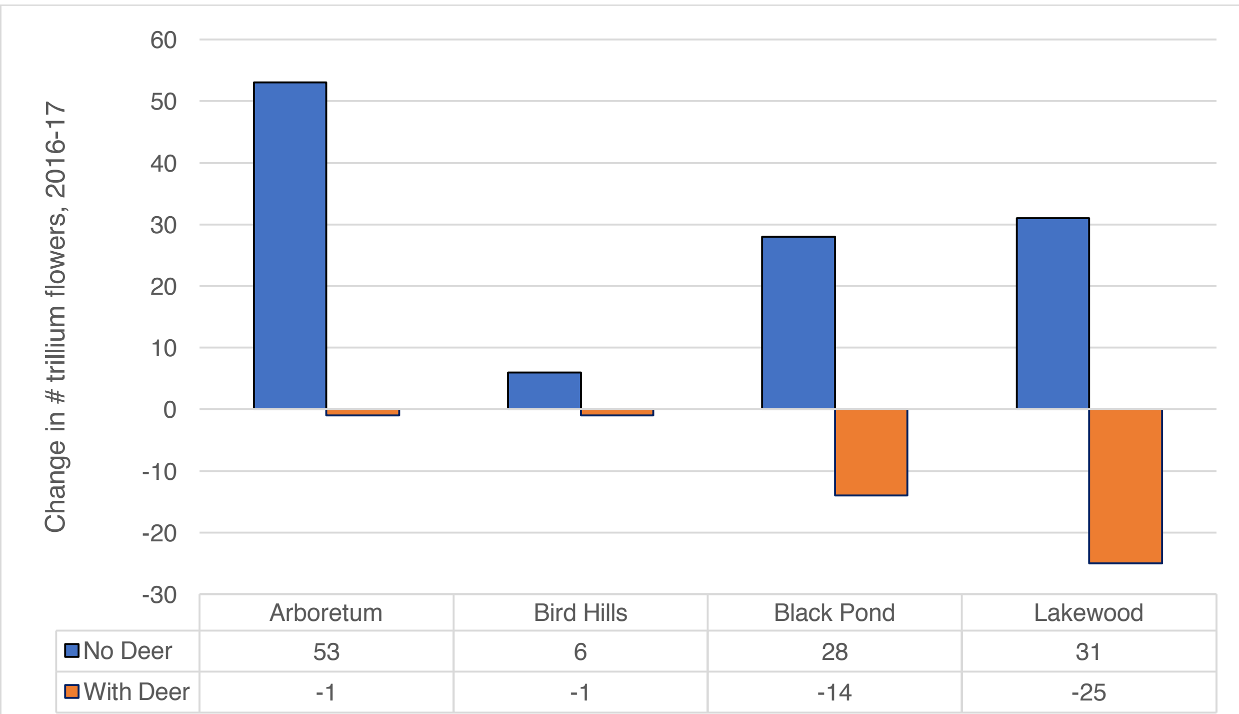


Figure 7. Change in trillium abundance from 2016 to 2017 at 4 sites in Ann Arbor. Negative numbers show population decreases. Deer were linked with total population decreases, at 4 sites. Plots with deer had fewer plants in 2017 than 2016, while plots protected from deer had more plants—these differences were highly significant (1-tailed t-test with unequal variance in Excel, p=0.001, indicating a probability of 1/10 of 1% that this difference could have occurred due to chance rather than the experimental treatment, fencing)**.**

Deer were linked with significant decreases in trillium flowering at 4 sites.

The total number of trillium flowers decreased from 2016 to 2017 in deer-accessible plots at 4 sites, compared to an increase in total flowering in fenced plots where plants were protected from deer (Figure 8). Flowering decreases associated with deer were particularly notable at Black Pond Woods and Lakewood. Flowering decreases in deer-accessible plots in Bird Hills were small due to the small initial number of flowers—among a total of 65 plants in deer-accessible plots, there was 1 flowering in 2016, and 0 flowering in 2017.[4]



	Arboretum	Bird Hills	Black Pond	Lakewood
No Deer	53	6	28	31
With Deer	-1	-1	-14	-25

Figure 8. Change in trillium flowering from 2016 to 2017 in 4 sites in Ann Arbor. Bars show difference in totals across plots from 2016 to 2017 in deer-accessible unfenced plots (orange) vs. fenced plots where plants were protected from deer. Negative numbers show that flowering decreased. Differences between fenced and unfenced plots were highly significant (1-tailed t-test with unequal variance in Excel, $p<0.0001$, indicating a probability of less than 1/100 of 1% that this difference could have occurred due to chance rather than experimental treatment, fencing). Bird Hills and the Arboretum show small decreases in flowering in deer-accessible plots partly because flower numbers were initially low: flowering dropped from 1 flower in 2016 to 0 in 2017 in plots with deer at Bird Hills, and from 10 in 2016 to 9 in 2017 at the Arboretum.

[4] The increase in flowering in fenced no-deer plots at the Arboretum may have been larger than at other sites because plots were fenced in December 2015, so they were fully protected throughout the 2016 growing season, whereas fences in other sites were constructed in April–May 2016, after some deer browsing had already occurred.

Deer were linked to lower trillium flowering rates (% flowering) at 4 sites.

While total number of flowers indicates floral (pollen and nectar) resources available for pollinators and other species, the proportion of plants that flower—reproductive or ***flowering rate***—indicates plant reproductive rates, and whether individual trillium populations are likely to increase or decrease over time. Flowering rates varied across sites, but deer were linked to lower flowering rates at 4 sites (Figure 9). Flowering rates at Black Pond Woods declined 16% in deer-accessible unfenced plots, compared to a slight increase in flowering rates where plants were protected from deer. At Lakewood, there was a small decrease in flowering rates in deer-accessible unfenced plots, but a 40% increase in fenced plots where plants were protected from deer, suggesting recovery from past deer impacts. Flowering rates at the Arboretum and Bird Hills were notably lower than at other sites, even in fenced plots protected from deer, which might indicate slow recovery from past browse damage.

Flowering rates allow a combined look at abundance and flowering. A low flowering rate can either represent an increase in the number of seedlings and young plants moving into the population, or a regression in plants that previously flowered but did not have enough resources available to flower in the current year. See full report for further results on flowering and abundance. Data that compare plant numbers and flowering together over 3 or more years will indicate underlying patterns; 2018 data will clarify trends.

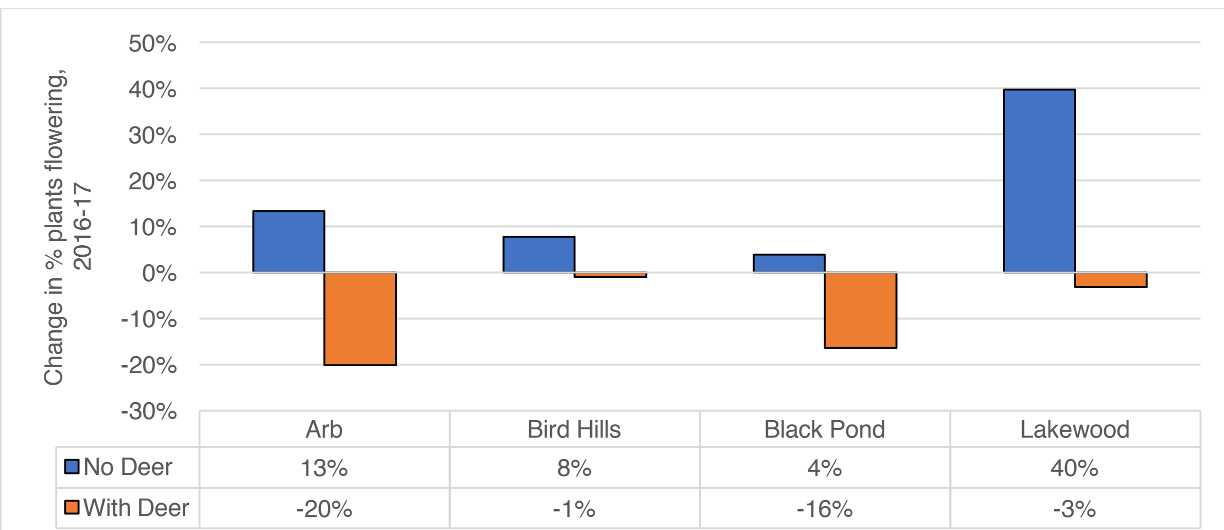
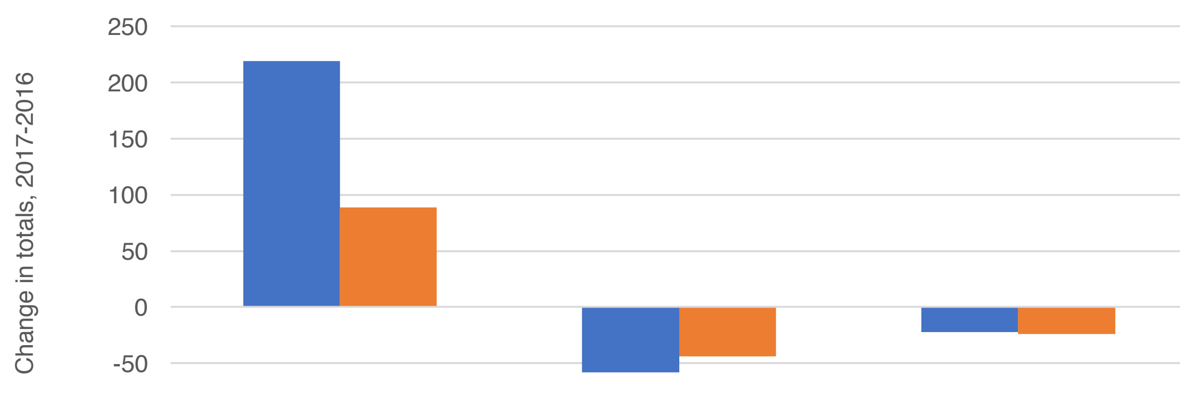


Figure 9. Change in trillium flowering rates from 2016 to 2017 in 4 sites in Ann Arbor. Bars show difference in totals across plots from 2016 to 2017 in deer-accessible unfenced plots (orange) vs. fenced plots where plants were protected from deer. Negative numbers show decrease in flowering rates. Flowering rates did not differ significantly between unfenced and fenced plots at the outset of the experiment in 2016, but were significantly lower in unfenced plots in 2017, and deer presence was linked with as significant reduction of flowering rates from 2016 to 2017 (1-tailed t-tests with unequal variance in Excel, p=0.003, indicating a probability 3/100 of 1% that this difference could have occurred due to chance rather than experimental treatment, fencing).

One site, Mary Beth Doyle, did not show clear patterns linked to deer.

Mary Beth Doyle had significantly higher initial trillium populations than other sites—two plot pairs had 150–300 trillium plants in a one-meter-square plot (10.8 square feet), compared to initial populations of 5–24 per square meter in Bird Hills, Black Pond Woods, and Lakewood, and up to 75 per square meter in Nichols Arboretum. High initial populations at Mary Beth Doyle could be due to environmental factors, such as soil type and land use history, and/or to lower intensity or duration of deer impacts.[5]

Trillium abundance, flowering, and flowering rates at Mary Beth Doyle differed from the other 4 sites, and did not show clear responses to deer. Trillium abundance increased in all plots—both fenced and unfenced—from 2016 to 2017, although the population increases were smaller in unfenced plots where deer were present (Figure 10). At the same time, the total number of flowers and the % of plants that flowered (flowering rate) decreased from 2016 to 2017 in both unfenced and fenced plots. None of the differences between fenced and unfenced plots were statistically significant.



	# plants	# flowers	% flowering
No Deer	219	-58	-22.38
With Deer	89	-44	-24.14

Figure 10. Changes in trillium abundance, flowering, and % flowering from 2016 to 2017 at Mary Beth Doyle. Data show the difference in the total number of plants, the total number of flowers (each plant produces one flower, so this is the same as the total number of flowering plants), and the proportion of plants that flowered. Due to high variability across plots and to large initial plant numbers, none of the differences in trillium abundance, number of flowers, and % flowering between fenced and control plots were statistically significant (1-tailed t-test with unequal variance in Excel, $p>0.05$, indicating a probability of more than 5% that these differences occurred due to natural variability or chance rather than due to the experimental treatment of fencing).

[5] There were more than 1200 plants in 10 one-meter-square plots at Mary Beth Doyle when plots were established in 2016, compared to 429 for 10 similarly sized plots at the Arboretum and 187 in 12 plots at Black Pond Woods, which had the next highest total population sizes sampled.

% CHANGE IN TRILLIUM ABUNDANCE AND FLOWERING

Relative to fenced plots, trillium decreased significantly in abundance and flowering from 2016 to 2017.

Presence of deer was linked to significant proportional reductions in trillium abundance between unfenced and fenced plots, relative to initial numbers (Figure 11). Deer were also linked to significant decreases in trillium % flowering at Black Pond Woods and Lakewood. Flowering was also lower in unfenced deer-accessible plots at other sites, although differences were not significant due to high variability. Flowering changed little at Arboretum and Bird Hills, likely because of lower initial flowering rates; the small difference between unfenced and fenced plots may suggest slow recovery from long-term deer impacts. Initial plot surveys at Bird Hills found deer browsing on 7–11% of stems per plot, a level that other studies have documented as leading to population declines (see p. 26, below, and full report). Photos at the Arboretum show that trillium flowering had already declined significantly between 2009 and plot placement in 2015.

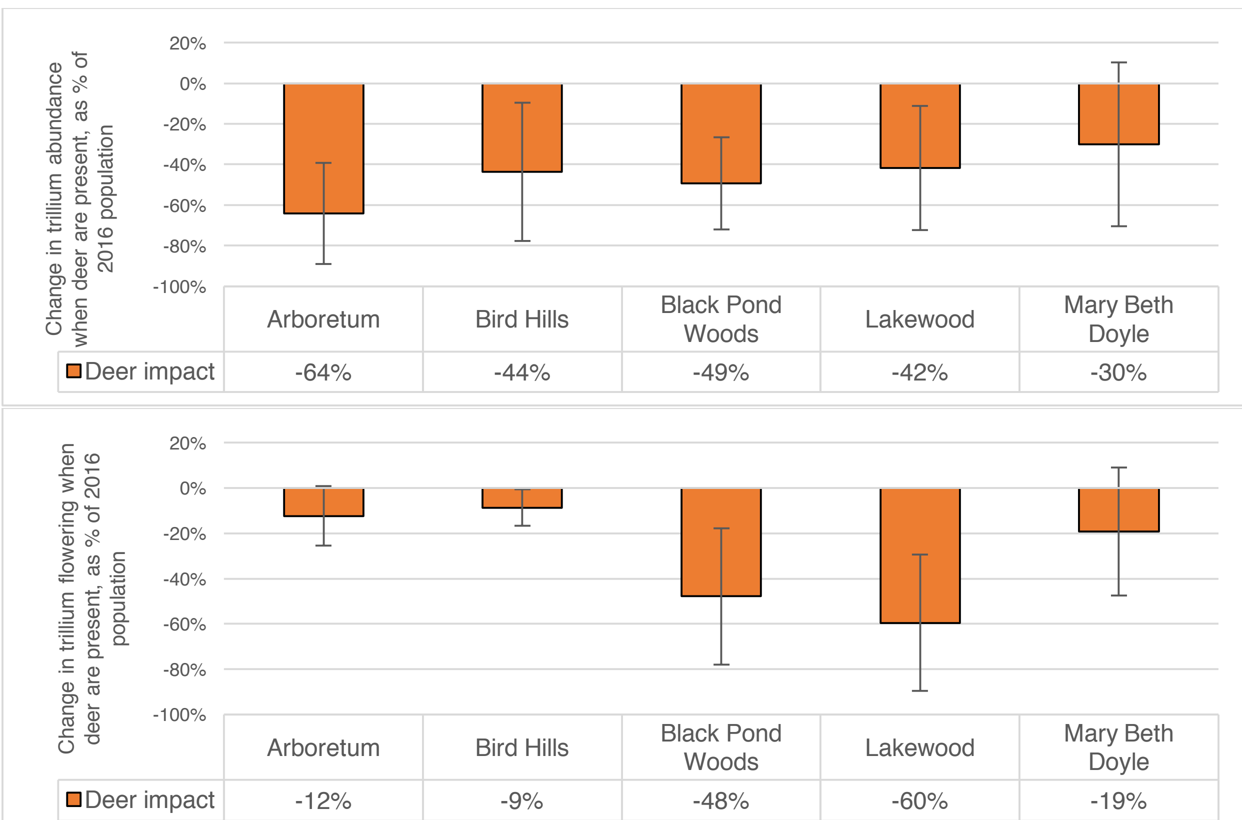


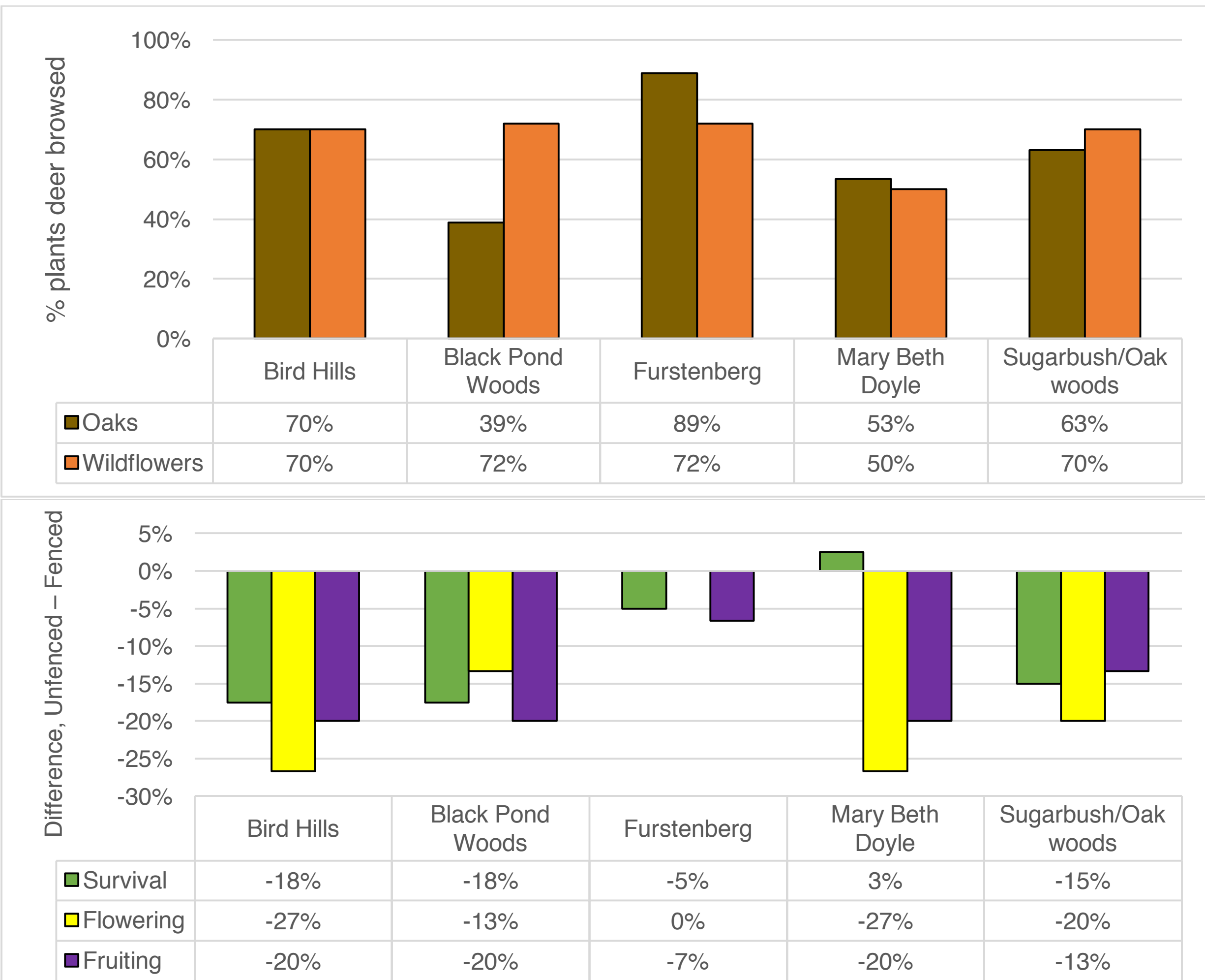
Figure 11. % change in trillium abundance & flowering from 2016 to 2017 at 5 Ann Arbor sites. The % change in number of trillium plants (above) and % flowering (below) relative to initial number**.** Bars show differences between unweighted averages for unfenced vs. fenced plots. Negative numbers indicate a decrease in abundance and flowering in plots accessible to deer, relative to plots protected from deer. Error bars are 95% confidence intervals of the mean. Decreased abundance and flowering associated with deer presence is statistically significant overall (paired 1-talied t-test in Excel, $p<0.03$ for abundance and flowering, indicating a less than 3% probability that result is due to chance), but comparisons within individual sites show that differences are only statistically significant at two sites.

COMPARISONS OF DEER IMPACTS ACROSS STUDIES

OAKS VS. WILDFLOWERS

Overall, deer browsing on oaks was similar to browse levels on wildflowers. Deer affected wildflower flowering and fruiting even where <60% oaks were browsed.

Deer browse rates on experimental oak and wildflower plants were quite similar (within 7% of each other) at Bird Hills, Mary Beth Doyle, and Sugarbush/Oakwoods. At Black Pond Woods, deer browsed a considerably higher proportion of wildflower plants than oaks in 2017 (72% compared to 39%), suggesting that oaks may be a conservative estimator of deer browsing on wildflowers at some sites (Figure 12). Even at the 3 sites with the lowest deer browse levels on oaks—Black Pond, Mary Beth Doyle, and Sugarbush/Oakwoods—deer were linked to decreased wildflower flowering and fruiting.



	Bird Hills	Black Pond Woods	Furstenberg	Mary Beth Doyle	Sugarbush/Oak woods
Oaks	70%	39%	89%	53%	63%
Wildflowers	70%	72%	72%	50%	70%

	Bird Hills	Black Pond Woods	Furstenberg	Mary Beth Doyle	Sugarbush/Oak woods
Survival	-18%	-18%	-5%	3%	-15%
Flowering	-27%	-13%	0%	-27%	-20%
Fruiting	-20%	-20%	-7%	-20%	-13%

Figure 12. % oaks and % wildflowers deer browsed vs. % surviving, flowering, and fruiting, 2017. Above, % plants deer browsed. Below, differences between total % mortality (decreased survival), flowering, and fruiting of wildflower experimental plants in unfenced (With Deer) less the total % in fenced (No Deer) plots in 5 Ann Arbor natural areas. Oakwoods and Sugarbush were paired for monitoring purposes because they are adjacent, separated only by Green Road.

Furstenberg was the one site where deer browsing was notably higher on oaks than on wildflowers. This may be partly due to seasonal effects—oaks were planted in December 2016 and many were browsed before dry weather started in June, whereas wildflowers were planted in late May and many plants wilted and died back between June and August, so that drought affected many wildflower plants before the deer did. Even so, deer browsing on individual wildflower species at Furstenberg was higher than the totals indicate, and more comparable to the browse levels on oaks: deer browsed 100% of the unfenced big-leaved aster and elderberry, and 80% of Canada anemone (see full report for full results by species and site). Although there was no difference in proportion of experimental plants flowering at Furstenberg, the total number of flowers in deer-accessible plots was much lower (2 flowers in unfenced deer-accessible plots vs. 25 in fenced plot—see full report). Therefore, although browsing on oaks was higher than on total wildflower stems at this site, the browse levels on oaks were still linked to significant decreases in total number of flowers and fruits.

Wildflower performance during this first year was not equal across all metrics, and was sometimes higher or lower than observed deer browse levels might suggest. Some impacts may accumulate over time, so data in 2018 will offer additional perspective. It is important to consider totals as well as differences.

OAKS VS. TRILLIUM

Deer impacts on trillium were significant even at sites with 45–52% of oaks deer browsed.

Deer browse levels of >60% of experimental red oak seedlings (averaged over the trillium monitoring period of 2016 and 2017) were linked to significant declines in trillium abundance at Bird Hills and Nichols Arboretum (Figure 13). (Trillium flowering did not decline notably at those sites, partly because flowering rates were already low). Deer browsing on oaks was lower at Black Pond Woods and Lakewood but was still linked to significant decreases in both trillium abundance and flowering. Deer browse rates on oaks may underestimate impacts on trillium, such as Lakewood. Levels of 45–52% of oaks deer browsed are associated with significant trillium declines.

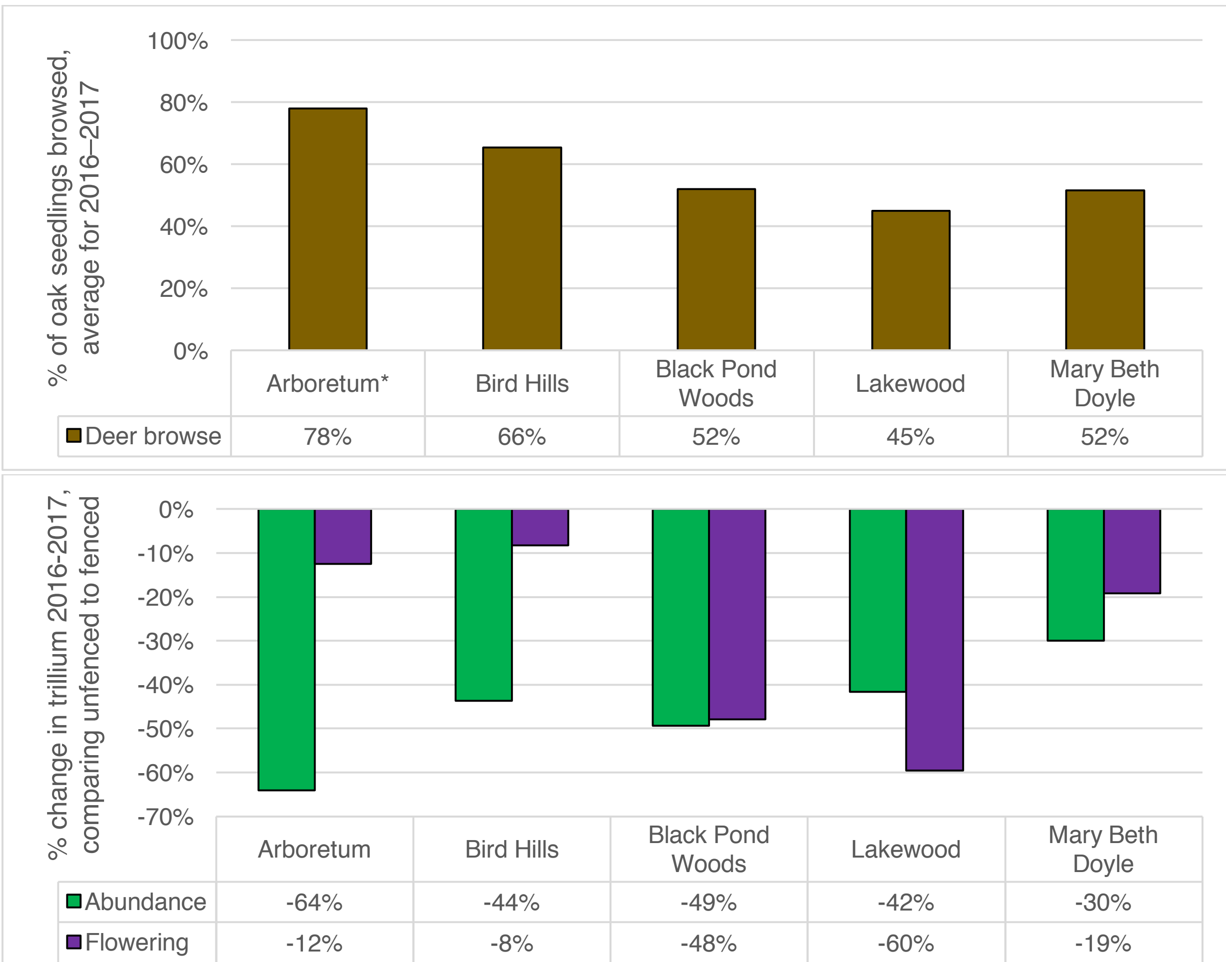


Figure 13. % oaks deer browsed vs. trillium abundance & flowering, 2016–17, 5 Ann Arbor sites. % oaks deer browsed (above) shows the combined average for 2016 and 2017, using the site-wide totals for Bird Hills (grouping Bird Road and Newport). *2017 oak data for the Arboretum is likely an underestimate because seedling plots were vandalized before final measurement. Relative differences in trillium abundance and flowering (below) shows an unweighted average of % difference in numbers of plants and flowers between unfenced and fenced plots, standardized by initial numbers (2016). Decreases show deer impacts (see Figure 11 and detailed explanation above, p. 20).

CHANGE IN VEGETATION IMPACTS FROM 2016 TO 2017

METRICS DO NOT YET SHOW CLEAR REDUCTIONS IN DEER IMPACTS

Data presented in this report show vegetation response to deer management activities in 2016 and 2017 but not yet 2018. It takes 3 years of data to establish trends.

Deer browse on oaks decreased from 2016 to 2017 in 2 deer-control sites but was still linked to reduced flowering of experimental wildflowers and trillium.

Where complete data for 2016 and 2017 can be compared, deer browse levels on red oak experimental seedlings declined at 2 sites near 2017 deer management areas: from 65% to 39% at Black Pond Woods (near Leslie Park Golf Course) and from 90% to 65% Bird Hills-Bird Road (Figure 14). (Deer browse in Bird Hills increased near Newport Road, however, so there was a net increase for Bird Hills combined.) Even with declines, deer browse on oaks was still considerably higher than 15%, the level above which oak forest regeneration is considered likely to fail.

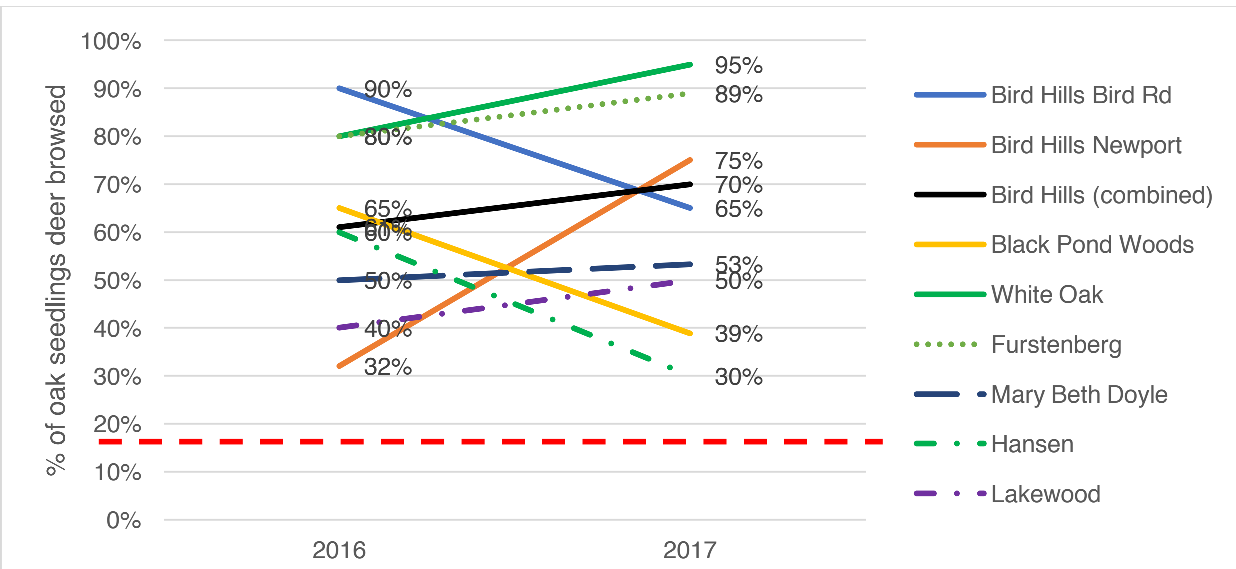


Figure 14. Change in % oaks deer browsed from 2016 to 2017 in Ann Arbor natural areas. Data for sites monitored for two full years. Browse levels at Bird Hills are shown separately for the Bird Road and Newport Road sites; Bird Hills (combined) shows the average for the full site. Natural areas are grouped by wards, which correspond to geographical areas: solid lines indicate natural areas in Ward 1 (north central), dotted lines are Ward 2 (northeast), small dashes and dots are Ward 3 (southeast), and large dashed line indicates Ward 5 (northwest). The red dashed line shows the 15% deer browse level above which oak forest regeneration is unlikely to succeed.

Even with reductions in % oaks browsed, deer significantly reduced experimental wildflower and trillium performance across the metrics measured. At both sites, deer were associated with reduced survival and flowering of experimental wildflowers, and reduced abundance and flowering of existing trillium populations:

- ***Bird Hills:*** wildflowers showed significantly increased % mortality and decreased % flowering and % fruiting, and trillium showed significantly decreased % abundance from 2016 to 2017, in deer-accessible unfenced plots compared to fenced plots (Figures 12 and 13, above).

- ***Black Pond:*** all metrics for wildflowers and trillium were significantly lower in unfenced deer-accessible plots, including % survival, % flowering, and % fruiting of experimental wildflowers in 2017, and % change in abundance and % flowering of trillium from 2016 to 2017 (Figure 12 and 13, above).

Therefore, deer management has not yet led to across-the-board reductions in deer impacts on vegetation in these sites.

Changes in deer browsing on oaks were notable at 2 additional sites.

Deer browse levels on oaks changed by 10% or more in 2 sites where deer were not managed—levels decreased at Hansen but increased at Lakewood. These changes serve as a reminder that deer browse may vary from year to year, and that a minimum of 3 years of data are needed to assess trends.

Deer browse levels on oak seedlings at Hansen decreased from 60% in 2016 to 30% in 2017. This site was selected for monitoring because it had lower deer abundance than many other natural areas (as recorded in the City's aerial 2016 deer survey and shown on the Ann Arbor Deer App). Deer were not managed at this site in 2017, so decreased browse levels cannot be attributed to management activities, although there were car-deer crashes reported along I-94 adjacent to Hansen in fall 2016 that might have reduced populations. No deer were noted there in the 2018 deer count on the Ann Arbor Deer App.

Deer browse levels on oak seedlings at Lakewood increased from 40% in 2016 to 50% in 2017, and that level of browsing was associated with a 42% relative decrease in trillium abundance and a 60% relative decrease in flowering (comparing unfenced deer-accessible populations to those protected by fences, in paired plots that had similar initial population sizes). However, the Ann Arbor Deer App shows no deer count data for Lakewood for 2015, 2016, and 2018, despite the fact that this nature area was within aerial survey measurement boundaries and was carefully observed in 2018. This serves as a reminder that deer count data from one or two days might not discover and count all deer that browse in a nature area during the course of a year. Furthermore, aerial deer surveys alone might not reveal all areas where deer are affecting vegetation in City natural areas.

CONCLUSIONS

Deer affected vegetation in Ann Arbor natural areas in 2017 by almost every metric and across sites: deer browsed 30% or more of red oak seedlings at all sites, and 50% or more at 11 City parks and natural areas monitored. Deer browsed 50–72% of experimental wildflower plants of 6 species at 5 natural areas. Comparisons of deer-accessible unfenced plots and fenced plots where plants and soil were protected from deer show that deer browsing and non-consumptive impacts (such as trampling, soil compactions, and microclimate changes), led to increased mortality across experimental wildflower species and sites, and decreased total flowering and fruiting rates of the two species of experimental wildflowers that grew enough to bloom. Abundance and flowering of naturally occurring wildflower species in experimental plots was also reduced. And a separate monitoring experiment showed reductions in trillium abundance, flowering, and flowering rates in unfenced, deer-accessible plots.

Existing research on oaks suggests that deer browsing on 15% or more of red oak seedlings per year is likely to inhibit successful forest regeneration (Blossey 2014, see p. 8), and demographic studies of trilliums have documented population declines, potentially leading to local die-offs, when deer browse levels are 5–15% (Rooney and Gross 2003, Knight et al. 2009).[6] Levels of deer browse that can be tolerated without leading to population declines are not known for many wildflower species. Continued monitoring in Ann Arbor will explore what levels are tolerated in Ann Arbor sites by experimental wildflower species and trilliums.

Apart from effects of deer browsing on oak regeneration and wildflower populations, however, deer-linked reductions in flowering and fruiting affect food and cover availability for a whole suite of pollinator species—bees, beetles, butterflies, moths—as well as other invertebrates, birds, and small mammals. As deer reduce resources for other species, this could lead to what scientists refer to as a "trophic cascade," in which species on various trophic levels are affected.[7] We do not yet know precisely the threshold of impacts that triggers a cascade. It does appear that at present levels, deer are exerting impacts that are likely to affect fauna species beyond the plants they directly consume.

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[6] Rooney, T. P. and K. Gross. 2003. A demographic study of deer browsing impacts on *Trillium grandiflorum*. *Plant Ecology* 168: 267. https://doi.org/10.1023/A:1024486606698; Knight, T.M., H. Caswell, and S. Kalisz. 2009. Population growth rate of a common understory herb decreases non-linearly across a gradient of deer herbivory. *Forest Ecology and Management* 257: 1095–1103.

[7] G. Palmer, P.A. Stephens, A.I. Ward, & S.G. Willis. 2015. Nationwide trophic cascades: changes in avian community structure driven by ungulates. *Scientific Reports* (5): 15601. doi:10.1038/srep15601