Monitoring Deer Impacts

on Natural Vegetation in Ann Arbor:

A Pilot Study of Red Oak Seedlings

as Experimental Indicators of Deer Browse Intensity (Sentinel Seedlings)

Across 10 Ann Arbor Natural Areas

November 2015–January 2017

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CONTENTS

FIGURES

TABLES

EXECUTIVE SUMMARY

This report presents results from a pilot study, conducted in Ann Arbor natural areas from November 2015 through January 2017, focused on developing a clear metric for deer impacts to vegetation and assessing current levels of browse damage. We used an experimental approach of planting red oak “sentinel seedlings” across sites and tracking the proportion of experimental oak seedlings browsed by deer. This approach, established in the Cornell study (Blossey 2014), offers a useful indicator of current deer browse intensity, and comprises a clear metric that can be repeated annually to track how deer browse damage changes in response to deer management efforts.

Key findings:

- **Deer damaged 61% of unfenced experimental seedlings overall,** with browse rates ranging from 20–90% depending on the park. This level exceeds the 15% recommended by Blossey (2014) as likely to reduce forest regeneration.

- **Deer browse affected the largest proportion of seedlings, and was most intense (with repeated browsing), in Bird Hills, White Oak, Furstenberg, and Nichols Arboretum.** Other sites with high browse damage include the Huron Hills Golf Course Nature Area and Huron Parkway Nature Area.

- **Deer did four times more damage than small mammals (including rabbits, chipmunks, and voles).** Deer damaged a higher proportion of seedlings than small mammals in all except one park (Fritz).

- **Most deer browsing on oak seedlings occurred between April and December.**

- **Unfenced seedlings accessible to deer were significantly more likely to die, and less likely to thrive (grow), than fenced controls.**

Recommendations for future monitoring

While this pilot study offers a useful metric and important initial data, three minor changes to the methods could improve the data: Using container-grown seedlings for more standard initial conditions and better transplant success; planting seedlings in spring, so that transplant mortality can be assessed and compensated for; and discontinuing use of fenced control plots (which served their purpose of demonstrating that red oaks survive and grow in sites when protected from deer) in order to assess more sites. In addition, more species could be monitored to yield a broader perspective on how deer are affecting diverse plants, including spring wildflowers and those important to pollinators.

BACKGROUND

One component of the Ann Arbor deer management plan is to “establish a baseline for measuring the vegetative impact of deer in the City’s natural areas and establish an ecological goal” (http://www.a2gov.org/departments/community-services/Pages/Deer-Management-Project-.aspx). This pilot study for the City of Ann Arbor comprises one method and presents data focused on two interrelated questions:

- What are baseline levels of deer browse damage to vegetation in natural areas in Ann Arbor city parks as of 2015–2016?
- What metric(s) can be used to periodically assess deer browse intensity and examine how deer management efforts are affecting it?

After considering various study methods, the City chose to do an experimental planting of red oak seedlings across natural areas in 10 city parks, initiated in November-December 2015. A preliminary report (October 2016) presented results from the first 9 months of monitoring. This final report presents from a full year of monitoring and additional analyses to address deer browse intensity and seedling survival and growth.

EXPERIMENTAL METHOD: RED OAK SEEDLINGS AS BROWSE INTENSITY INDICATORS

Several major methods are available for assessing deer impacts on diverse plant species over time (outlined in an earlier report, Courteau 2015). We selected an ***experimental browse intensity indicator*** or “sentinel seedling” method—planting red oak seedlings across a range of sites and monitoring them for browse damage over the course of the year (Blossey 2014). This method offers a clear and repeatable metric with the following characteristics:

- Provides initial **local** and **site-specific** data on deer browse intensity.
- Offers **standardized measurement in a single clear metric** across various sites.
- **Distinguishes deer damage from other sources of vegetation change**.
- Can be repeated annually to assess how deer management efforts are altering deer impacts on vegetation.

The experimental design used in this study was developed by Blossey and others for use in Ithaca (the “Cornell study,” Blossey 2014), and have been applied in various other communities and park systems. We previously used similar methods to assess impacts of deer and other mammalian herbivores on two native tree species (Courteau 2005).

Why use red oaks?

Red oak (*Quercus rubra*) was selected as the experimental species for several reasons:

- The species naturally occurs in **all** city natural areas assessed.

- It comprises an ecologically meaningful measurement because it represents a key Ann Arbor ecological community (oak/hickory forests) and important ecological functions (tree and forest regeneration, habit, food source for many species).

- Oak regeneration has been declining in much of Michigan and the northeastern U.S., concerning many forest scientists and conservation managers (Lee & Kost 2008, Abrams 2003).

- Red oak is a species of **intermediate** deer preference—not the first and most nutritious food to be browsed by deer, so it doesn't represent the most sensitive species (MI DNR), but not the last food either (Blossey 2014). Because this species is not highly preferred, it offers a somewhat conservative indicator.

- Nursery seedlings and acorns of Michigan genotype are readily available.

Deer browse damage on oak seedlings can be distinguished from small mammal damage.

While deer browse may affect many wildflower species that are also of interest for their ecological importance (providing resources for pollinators including butterflies and bees, as well as various species of birds), the advantage of using a woody species, such as red oak, is that deer browse damage on woody stems can be readily distinguished from browse damage by other mammals that eat tree seedlings (Salmon & Passof 1989, UK Forestry Commission 2017).

- Deer lack upper front teeth (incisors), so their browsing leaves a ragged edge with a "shreddy" appearance. Browsing most often occurs at heights of 2–3 feet, but may be done at heights as low as 2" or as high as 6.'

- Rabbits and woodchucks have large and sharp incisors that leave clean cuts, generally at a 45° angle. Browsing most often occurs at heights of 3–16", but may be done at heights of up to 3' in years with heavy snow cover.

- Voles and mice chew on bark, and voles may chew through whole stems, within 3" of ground level or below-ground, leaving small tooth marks less than 1/8" wide.

Figure 1. Deer browse in comparison to rabbit and vole damage. Deer produce "shreddy" cut, in contrast to clean, clearly angled rabbit (or woodchuck) damage (upper photo) and the toothy gnawing by voles and mice (lower photo).

Photo credits: Deer vs. rabbit browse, http://octrackers.com/analyzingtherabbittrack.htm; vole damage, Missouri Botanical Garden (http://www.missouribotanicalgarden.org/gardens-gardening/your-garden/help-for-the-home-gardener/advice-tips-resources/pests-and-problems/animals/voles.aspx).

Figure 2. Deer vs. small mammal damage in Ann Arbor experiments.
a) Deer browse with characteristic shreddy edge. b) Rabbit browse with angled edge.
c) Seedling gnawed through by vole, near ground level; stem left behind.

a. b. c.

Photos: J. Courteau.

How does deer browsing affect red oak seedlings? Why is the proportion of seedlings browsed important?

Numerous studies over the past two decades have reported that deer browsing leads to forest regeneration declines.[1] Although many plant species can tolerate moderate levels of herbivore damage, deer browse on woody plant buds and branch tips is likely to affect the apical meristem tissue key to plant growth (Reznicek, pers. comm., June 2015). Mammalian browse damage makes seedlings more susceptible to drought, disease, and insect attacks. My previous research has shown that browsing on tree seedlings by any mammalian herbivore (generally, when full stems are clipped) leads to a significant increase in mortality in the following season (Courteau 2005). Others have found that browsing that affects 50% or more of woody sapling buds or branches is likely to lead to mortality (Winchcombe 2016).

The proportion of tree seedlings that are browsed each year is a key indicator of forest regeneration impacts. As noted by Blossey (2014), tree regeneration declines when more than 15% experimental 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.

Therefore, the metric used in this report—the proportion of experimental oak seedlings browsed by deer—provides a useful indicator of current deer browse intensity and offers a clear metric that can be repeated annually to track how browse intensity responds to deer management efforts.

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.

Blossey (2014) monitored existing trillium populations, rather than experimental plantings, as have many studies in urban areas and parks including Montgomery County, Maryland (1995), Swarthmore College (Latham 2013), and Cuyahoga Valley National Park (National Park Service 2015). A separate study to assess deer browse damage on trillium in Ann Arbor natural areas was initiated in spring 2016, and preliminary results will be available in summer 2017.

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[1] Several major studies and reviews that describe deer impacts on forest vegetation and other wildlife species include Strohmayer & Warren 1997, Rooney & Waller 2003, Rawinski 2008, Rawinski 2014, Frerker, Waller & Sabo 2014, and Pendergast et al. 2016.

PILOT STUDY METHODS

SITE SELECTION AND SEEDLING INSTALLATION

We planted 370 red oak seedlings in 10 city park natural areas from November 30–December 16, 2015, as shown in Figure 3 and Table 1. One city park natural area (Bird Hills) was large enough that seedlings were planted in 2 separate areas of the park, indicated as Bird Hills Newport (near M-14 and the Newport Road park entrance) and Bird Hills Bird Road (near Huron River Drive and the Bird Road park entrance).

In addition to city parks, University of Michigan Nichols Arboretum (Bob Grese, director) contracted a separate study of deer impacts in the Arb using the same monitoring protocol with 50 red oak seedlings, and they have generously agreed to share their data. This report shows results for both studies, a total of 420 seedlings.

Sites were selected with several criteria:

- to encompass a range of large and smaller parks, including those with high-quality natural areas (such as Bird Hills, Mary Beth Doyle, Black Pond Woods);

- to represent areas found in the 2015 aerial survey to have higher and lower deer densities; and

- to achieve geographical coverage of the city.

Natural areas are not evenly distributed throughout the city, and we were not able to assess any natural areas in Ward 4, which lacks public spaces with mature oak forests other than Pioneer Woods (which is owned by Ann Arbor Public Schools).

Within each natural area, we selected planting sites in mature oak forests (typically dominated by red and/or white oaks, and occasionally black oak), on level to moderately sloping ground, where ground vegetation was open enough to permit access by deer (and by researchers). We aimed to place seedlings at least 15' from trails to minimize human impacts, but a few seedlings are closer to trails in the smaller parks.

The general goal was to plant 40 seedlings per site in paired plots (half fenced and half unfenced) so that there would be 20 unfenced seedlings to assess for each natural area. We planted more seedlings in larger sites (Bird Hills Park and Nichols Arboretum). Fewer seedlings were planted in the three smallest parks (Fritz, Huron Hills Golf Course Nature Area, and White Oak), and in the Bird Road section of Bird Hills.

Figure 3. Experimental planting sites (monitoring locations). Map: Natural Area Preservation.

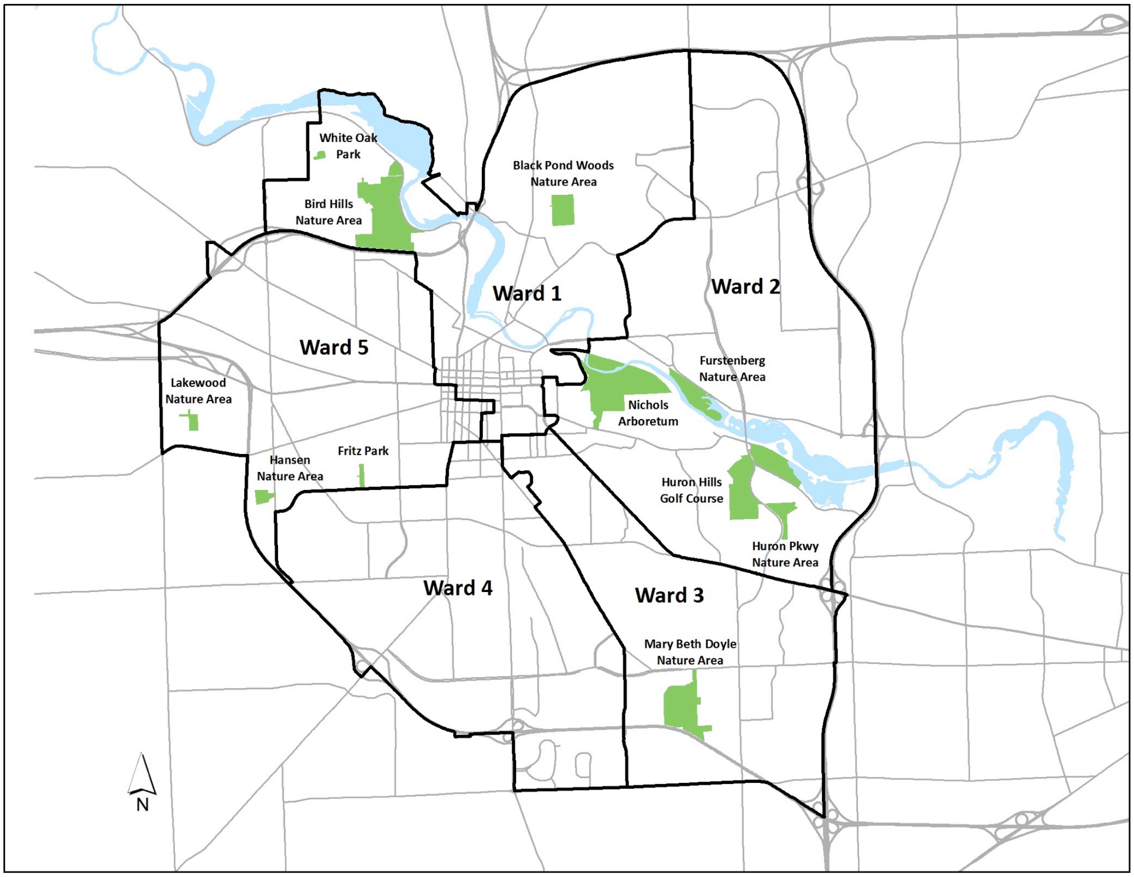


Table 1. Sites and seedling numbers. Seedlings were planted at 9 Ann Arbor natural areas (2 sites within Bird Hills) and the University of Michigan Nichols Arboretum.

WARD	SITE	TOTAL OAK SEEDLINGS	# FENCED	# UNFENCED
1	Bird Hills/Bird Road	20	10	10
1	Bird Hills/Newport	50	25	25
1	Black Pond Woods	40	20	20
1	White Oak	20	10	10
2	Arboretum	50	25	25
2	Furstenberg	40	20	20
2	Huron Hills Golf Course	20	10	10
2	Huron Parkway	40	20	20
3	Mary Beth Doyle	40	20	20
5	Fritz	20	10	10
5	Hansen	40	20	20
5	Lakewood	40	20	20
	TOTAL	420	210	210

FENCED CONTROL PLOTS

For this pilot study, one half of the 420 seedlings were fenced to protect them from deer but allow access by small mammals, so that survival and growth of seedlings affected by deer could be compared to a control group. Fences were 18” diameter by 4’ tall cylinders of 2” X 4” welded wire mesh, secured to 3’ garden fence posts. Within each seedling pair, seedlings were randomly selected for fencing. Seedlings were placed in paired plots at roughly 15’ intervals along a transect, with the direction and distance from the transect randomized (within 5’ to 12’), to avoid creating a discernible pattern, and unfenced seedlings were not marked with flags or tags that deer could learn.

Fences did not completely exclude deer: 13% of fenced seedlings showed evidence of deer browse on seedlings at or just inside the fence edge. However, damage was less extensive on fenced seedlings with fewer twigs and buds, or only leaves browsed.

EXPERIMENTAL SEEDLINGS

Red oak experimental seedlings were nursery-grown Michigan genotype seedlings in the 12-18” size class, obtained as bare-root stock from Cold Stream Nursery in Free Soil, Michigan. Seedlings in the height class varied considerably in age, diameter, and branching patterns, and many had signs of pruning as well as previous browse damage by deer and/or rabbits. To distinguish initial damage from browsing that occurred after planting, initial damage was marked with water-resistant paint and all seedlings were photographed at planting time for comparison to later assessments. Seedlings were paired by size and branching patterns to the extent possible.

Seedling condition was difficult to assess accurately during the winter dormant state, and it was not possible to determine transplant mortality (death within the first month) during the winter or compensate for it by replanting once the ground had thawed.

MONITORING

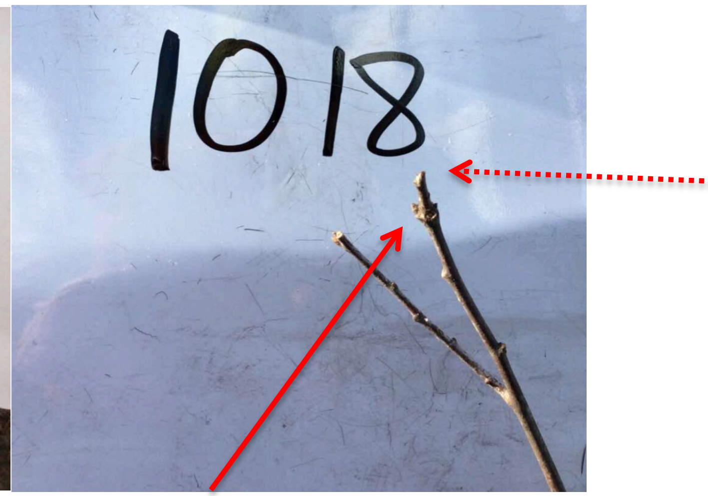
Seedling planting locations and initial height were documented on the ArcGIS Collector app, and photos were taken to show initial condition and allow for comparison to later measurements (Figure 4). Seedlings were monitored five times during 2016 to evaluate survival and condition during a full year, and to assess browse damage (Table 2).

All browsed seedlings were measured to characterize browse damage (height, number of branches browsed) and examined carefully using a 10X hand lens to identify the browser (deer vs. small mammal, including rabbits/woodchucks, voles/mice, and squirrels/chipmunks) and a photo was taken. Additional notes were taken on insect damage, wilt or dieback (likely from drought), and damage from other sources (including fallen tree limbs and vandalism).

Figure 4. Seedling monitoring: Before and after photos of experimental red oak seedling: a) At planting time, December 2015. b) At second monitoring time, April 2016. Red arrows indicate the deer-browsed branch. In photo b), shredded bark is just visible at edge where deer browsed buds and part of stem (dotted line), and seedling lacks the sharp angle characteristic of rabbit or woodchuck browse.

a.

b.



Photos: J. Courteau.

Table 2. Planting and monitoring dates for red oak experimental seedlings.

Planting:	Nov 30–Dec 16	2015
Monitoring 1:	Jan 6–Feb 5	2016
Monitoring 2:	Mar 14–April 6	2016
Monitoring 3:	May 29–Aug 1	2016
Monitoring 4:	Aug 4–Sept 21	2016
Monitoring 5*:	Dec 9–30, Jan 9, 19	2016–17

* The final monitoring aimed to assess seedlings one year after planting, and most sites were measured within one year ± 2 weeks. Technical difficulties delayed final measurements at two sites to 3–5 weeks.

DATA ANALYSIS

Data compiled in Collector was exported to Excel for compiling descriptive statistics (averages, totals, cumulative totals) and comparing browse proportion across sites. Data on survival, condition, and growth were not continuous and normally distributed, so they were analyzed with a Chi-square analysis, rather than Student's t-test or analysis of variance (ANOVA).

This report includes data for all 420 seedlings are analyzed for survival, condition, and growth, as well as overall mammal damage. However, all analyses of browse damage focus on the 210 unfenced seedlings. Deer browse damage on fenced seedlings is not included that analysis because the experiment was set up to compare unfenced vs. fenced seedlings.

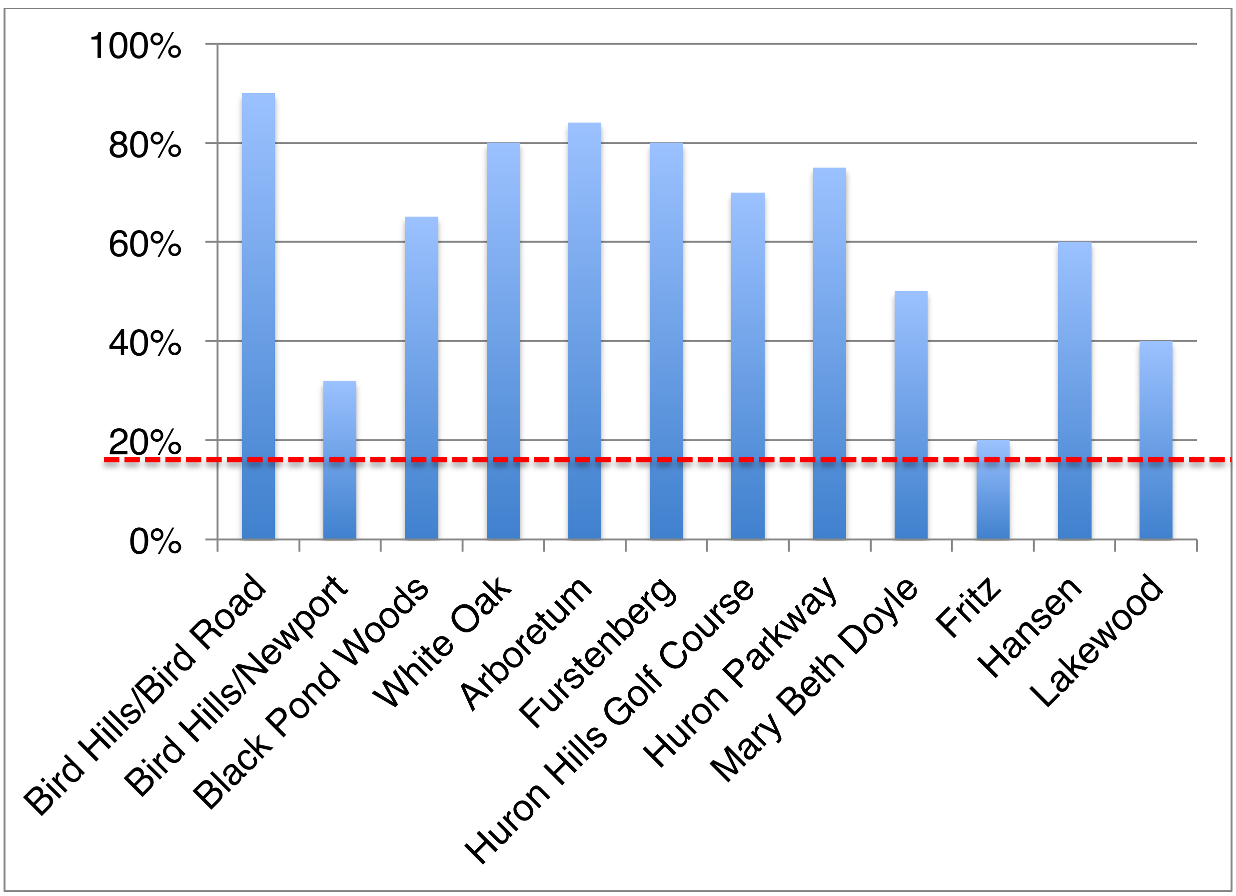
KEY FINDINGS

HOW MUCH BROWSING DID DEER DO?

Deer browsed 61% of unfenced experimental red oak seedlings.

Overall, 61% of seedlings accessible to deer (unprotected by fencing) were browsed by deer at least once. Browse damage ranged from 20%–90% across sites. More than half of the sites had 60% or more seedlings browsed. Browse of more than 15% of seedlings per year is likely to interfere with forest regeneration (Blossey 2014).

Figure 5. Proportion of experimental red oak seedlings browsed by deer. The dotted red line indicates the 15% annual browse level above which forest regeneration is unlikely to succeed (Blossey 2014). This figure shows data only for unfenced seedlings; it does not show the 28 fenced seedlings that were browsed by deer.



Ward 1 Ward 2 Ward 3 Ward 5

*NOTE: Monitoring in the Arboretum was a separate study, commissioned and paid for by University of Michigan Matthaei Botanical Gardens & Nichols Arboretum (UMBGNA); data are included here for reference, courtesy of Bob Grese and UMBGNA.

WHERE DID DEER DO THE MOST DAMAGE?

Browse intensity (repeated browsing) was highest in Bird Hills, White Oak, Furstenberg, and Nichols Arboretum.

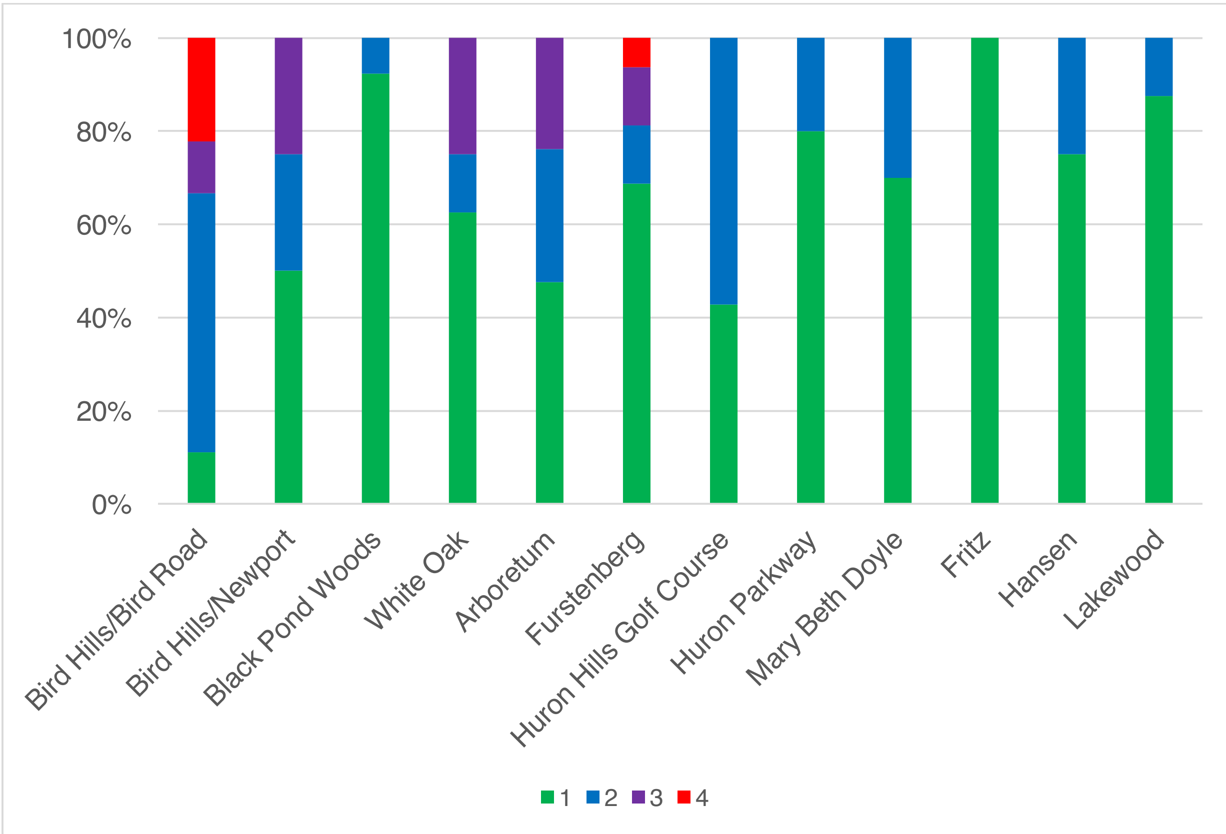
Any browse damage can make tree seedlings more susceptible to drought, insects, and other stressors, but the greater the browse damage, the harder it can be for seedlings to recover; browse damage levels of 50% or more of the branches or buds on a tree seedling are likely to lead to mortality (Winchcombe 2017). Although this pilot study was focused on ***whether*** seedlings were browsed, rather than ***how much***, the 2015–16 data provide an initial indication of browse intensity. At each monitoring period, new browse damage was recorded, so the number of browse incidents can be tallied.[2]

Of seedlings that were browsed by deer, most were browsed once or twice during the year (88% of unfenced deer browsed seedlings, Figure 6). However, 12% of seedlings, in 5 sites, were browsed 3 or 4 times. Natural areas in the Northeast and Northwest sections of the city (Wards 1 and 2, including Bird Hills, White Oak, Furstenberg, and Nichols Arboretum), had the highest browse intensity.

A comparison of browse proportion (Figure 5, above) and browse intensity (Figure 6, below) shows that, in most cases, sites where seedlings were browsed repeatedly by deer were those where a high proportion of seedlings were browsed. One exception to the pattern is Bird Hills/Newport Road, where around 30% of seedlings were browsed, but half of them were browsed 2 or 3 times. This suggests that within the larger Bird Hills site, deer were browsing in certain areas more than others. Rawinski (2014) has noted that the spatial distribution of deer browse ("herbivoclines") may be due to proximity to roads and trails, steep slopes, presence of people, and other factors.

[2] Initial seedling condition was highly variable and it was not possible to assess (on dormant seedlings) how many living branches were available to be browsed in order to calculate the % of browse damage on each plant. However, the number of browse incidents (# of times browsed) serves as an indicator of browse intensity.

Figure 6. Browse intensity: number of times unfenced seedlings were browsed by deer. For those seedlings that were browsed by deer, this figure shows the proportion of seedlings that were browsed 1, 2, 3, or 4 times.



Ward 1 Ward 2 Ward 3 Ward 5

HOW DID DEER BROWSE COMPARE TO DAMAGE FROM OTHER HERBIVORES?

Overall, deer browsed 4 times as many seedlings as did small mammals.

Oak seedlings may be browsed by various mammalian and insect herbivores, so we assessed and compared browse damage from deer to damage by other herbivores—small mammals and insects. This study found damage to woody stems of oak seedlings from a range of small mammals, including rabbits/woodchucks, voles/mice, and squirrels/chipmunks.[3] Insect damage on leaves was assessed separately.

Both deer and small mammals damaged the experimental red oak seedlings, but deer damaged 4 times as many seedlings. Out of 210 unfenced experimental seedlings, 151 (72%) showed signs of any mammal damage. Deer alone damaged 52% of seedlings, while another 9% of browsed seedlings were affected by both deer and small mammals (Table 3), for a total of 129 seedlings (62%) browsed by deer. Small mammals alone were responsible for damage on 13 seedlings (6%); with the 19 seedlings (9%) that were also browsed by deer, 32 seedlings (15%) showed small mammal damage.

Table 3. Number of seedlings browsed by deer compared to other mammalian browser. A total of 151 out of 210 unfenced seedlings were browsed at least once by a mammalian browser. Some seedlings were browsed more than once, either by deer, by deer and small mammals, or in a few cases, by different small mammals. The "Other" category includes cases in which the cause of the damage could not be classified with certainty, including several cases that were likely deer browse or deer trampling but for which browse marks were ambiguous.

Browser identity	# seedlings browsed	% of 210 unfenced seedlings	% of 151 browsed seedlings
Deer only	110	52%	72.8%
Deer + small mammal	19	9%	12.6%
Small mammal only	13	6%	8.6%
Other/not clearly identifiable	9	4%	6.0%
Total # seedlings browsed	151	72%	

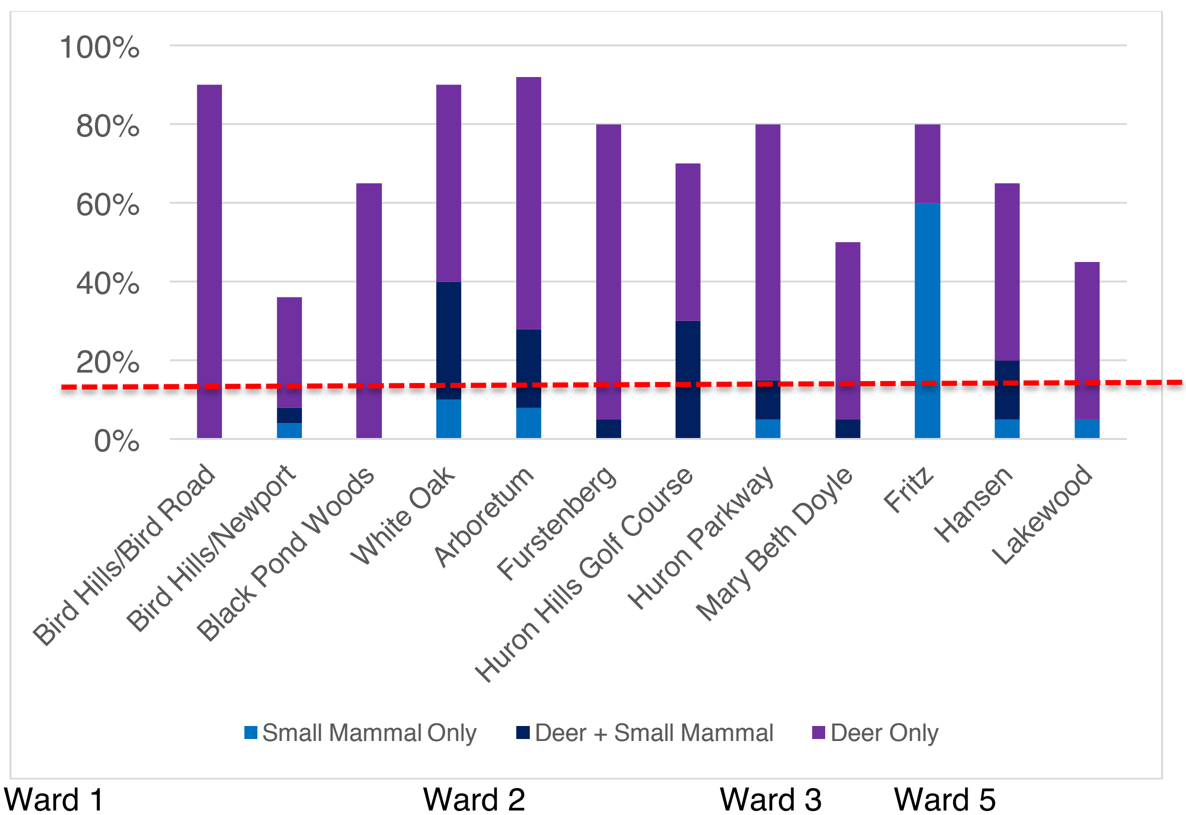
[3] Small mammals that chewed on experimental seedlings included rabbits/woodchucks, squirrels/chipmunks, and mice/voles. Rabbits and woodchucks, as well as squirrels and chipmunks, may clip off woody stems and branches with sharp incisors. Mice and voles nibble bark of woody stems, and voles may chew through whole stems at ground level or below. Rabbit and woodchuck damage are grouped, as are squirrel and chipmunk damage, because browse damage is similar in pattern and impact, and hard to differentiate based on browse scars alone. Droppings and other signs suggest that the rabbit/woodchuck damage was primarily by rabbits, while squirrel and chipmunk signs were both observed. Damage by insects on leaves was categorized separately; caterpillars (such as gypsy moths) and sap-sucking aphids can chew through or mine leaves, potentially defoliating significant portions of tree seedlings.

Deer damaged more seedlings than did small mammals in all except one site.

Overall, the proportion of seedlings damaged by small mammals was much lower than the proportion browsed by deer damage (Figure 7). Some small parks (such as Fritz, Huron Hills Golf Course, and White Oak) had relatively larger proportions of seedlings damaged by small mammals. Fritz was the only site where damage by small mammals was greater than damage by deer.

Some seedlings were browsed by both deer and small mammals. In many cases where this occurred, rabbits browsed seedlings over the winter, the seedlings resprouted in the spring, then deer browsed the resprouts.

Figure 7. Proportion of experimental red oak seedlings browsed by deer vs. small mammals. The dotted red line indicates the 15% annual browse level above which forest regeneration is unlikely to succeed (Blossey 2014).



OTHER FINDINGS

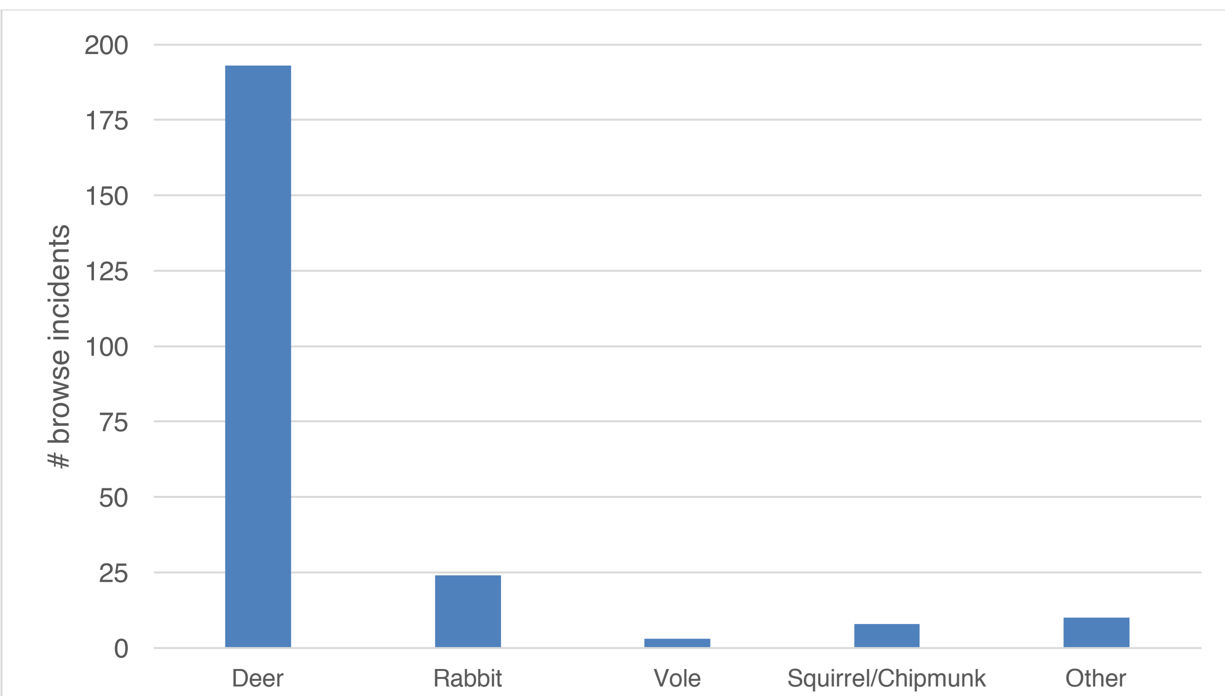
The incidence of deer browse was more than 4 times higher than that of other mammalian herbivores.

All new browse damage was recorded at each monitoring period as a “browse incident”; a seedling could have multiple browse incidents if browsed more than once or by different animals. In all, 238 browse incidents were observed on the 210 unfenced seedlings.

Deer browse incidents comprise 81% of the total, more than four times as many as from all types of small mammals combined. Rabbits make up 10% of the total, squirrels/chipmunks were 3%, and voles/mice were just over 1% of the total. The “Other” category includes cases in which seedlings may have been trampled by people as well as several in which the cause of the damage could not be classified with certainty, including several cases that were likely deer browse or deer trampling but for which browse marks were somewhat ambiguous.

(This analysis is focused on damage to unfenced seedlings and does not include the 28 fenced seedlings that were browsed by deer.)

Figure 8. Proportion of browse incidents on unfenced seedlings by deer compared to small mammals. Any new browse damage noted during a monitoring period was counted as a “browse incident.”

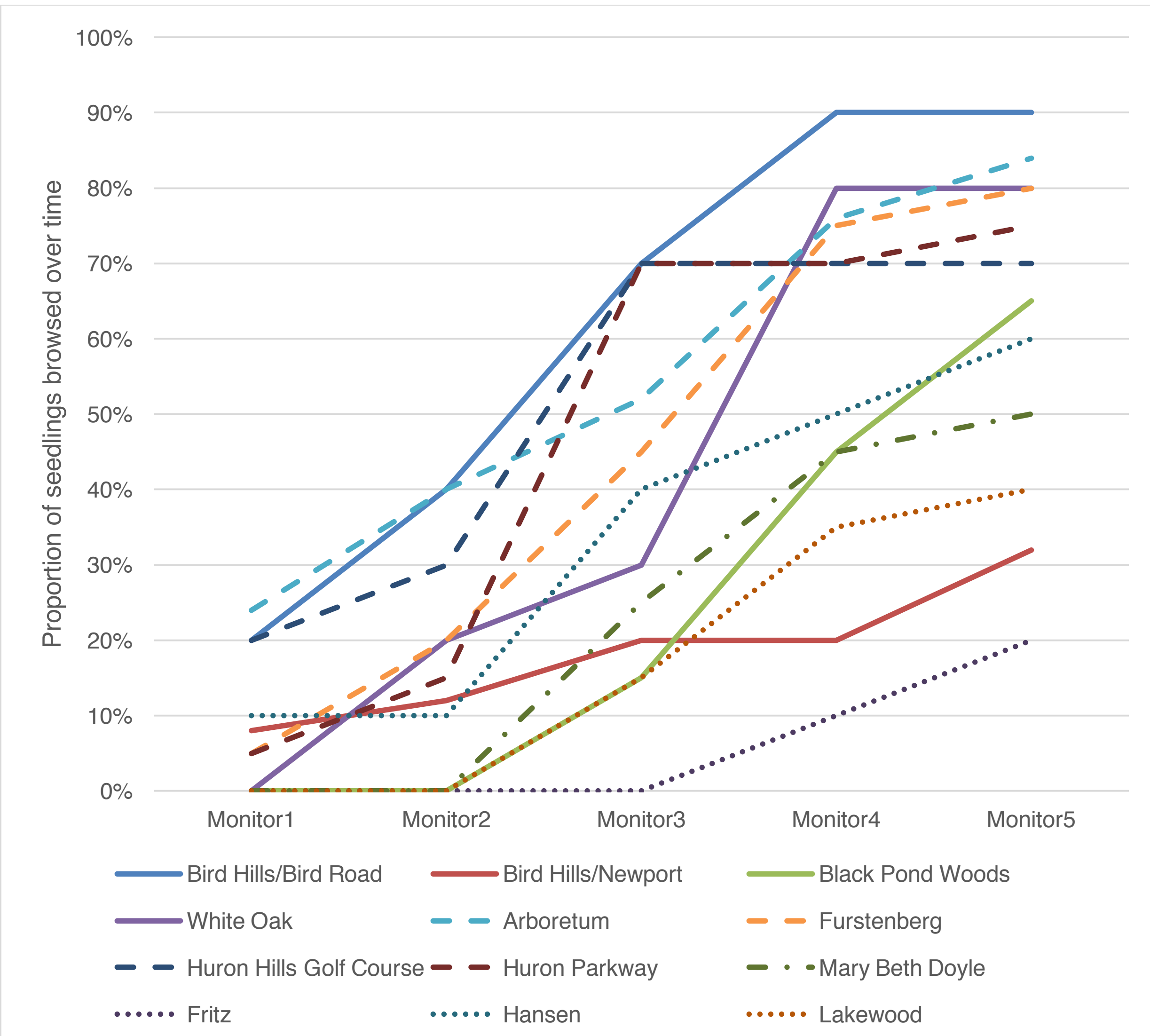


WHEN DID BROWSE DAMAGE OCCUR?

Most seedlings were browsed by deer between April and December rather than during the winter.

The seasonal patterns of deer browsing varied somewhat across parks. In general, at parks with the highest overall browse intensity, seedlings were first browsed relatively soon after planting and early in the year, while at some parks, seedlings were browsed throughout the year (Figure 9). Small mammal browse (not shown here) showed a different pattern, with most rabbit damage occurring during winter (January through April), and squirrel/chipmunk occurring during summer (late May through September).

Figure 9. Cumulative deer browse damage over time. Proportion of the 210 unfenced seedlings browsed over the course of the different monitoring periods.



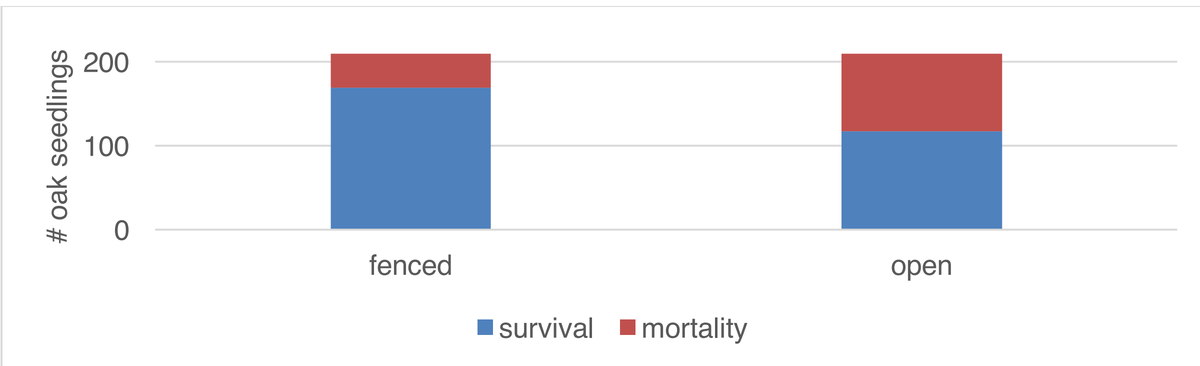
SEEDLING SURVIVAL AND GROWTH IN OPEN VS. FENCED CONTROL PLOTS

Fences did not completely prevent deer from browsing seedlings, and somewhat limited small mammal access. However, the experimental design of paired plots, with fenced seedlings serving as a control with deer mostly excluded, allows for comparisons of seedling survival and growth.[4]

Unfenced seedlings open to deer were more likely to die than fenced controls.

Total seedling mortality across all sites where deer were allowed was 44%, compared to 20% for fenced controls (Figure 10). A chi-squared analysis shows that this difference is significant ($p<0.01$; $\chi^2=29.63$, d.f.=1), with a probability of less than 1% that the result is due to random chance or natural variability.

Figure 10. Total proportion of survival and mortality of fenced vs. open seedlings. Totals for the 210 fenced seedlings compared to the 210 open (unfenced).



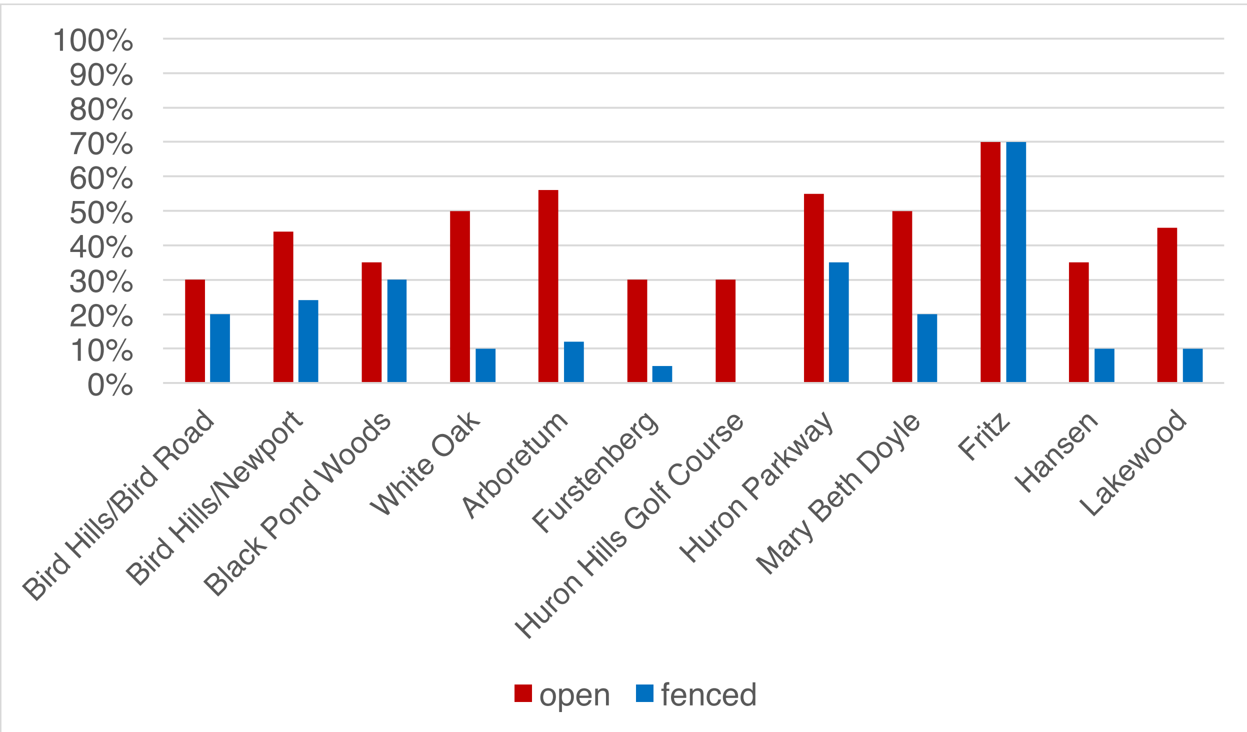
Insects and drought may have contributed to mortality, but effects would have been similar across fenced and unfenced seedling pairs (6–20 feet apart). Leaf damage by caterpillars (likely gypsy moths) was notable in May and June. Estimated damage on most seedlings was less than 10% of total leaf area, but 8% of seedlings had 50% or more leaf area removed. There was limited rainfall during the growing season: although drought was not officially declared, the months of April through July 2016 all had below-average rainfall, and there was no rain at all for 5–6 straight weeks during July and early August. Many experimental seedlings (and other plants at study sites) showed drought stress, including severe wilt and dieback. Several seedlings were also damaged by vandalism (2–3 fences were smashed and seedlings broken) and by trees or large limbs that fell during storms and high winds (8–10 seedlings bent, but only 1 broken).

[4] There were 28 deer browse incidents on fenced seedlings (13%), where seedlings either leaned against the fence or deer pushed through fence openings, but damage was typically less than on unfenced seedlings. Bird Hills/Bird Road, Furstenberg, and Huron Hills Golf Course Nature Area all had 20% of fenced seedlings browsed by deer. Fences were designed to allow access by small mammals, but somewhat reduced their activity: small mammal browse incidence was lower inside than outside fences (10 browse incidents vs. 45). Small-diameter fences with 2X4” mesh were used to reduce costs and site disruption.

Seedling mortality was higher in unfenced deer-accessible vs. fenced control plots in all but one site (Fritz Park).

Seedling mortality ranged from 30–56% by site of unfenced seedlings accessible to deer, and from 0–35% by site where seedlings were fenced, except at Fritz Park, where both fenced and unfenced seedlings had a mortality rate of 70%.

Figure 11. Seedling mortality of unfenced (open) vs. fenced seedlings by site.



Variation in seedling mortality across sites could have been due, in part, to poor initial seedling condition: the bare root seedlings shipped and planted on different dates appeared to vary in vigor, although condition can be hard to accurately assess when seedlings are dormant. A summary analysis of seedling condition at first monitoring period vs. survival did not show clear patterns across fenced and unfenced plots.

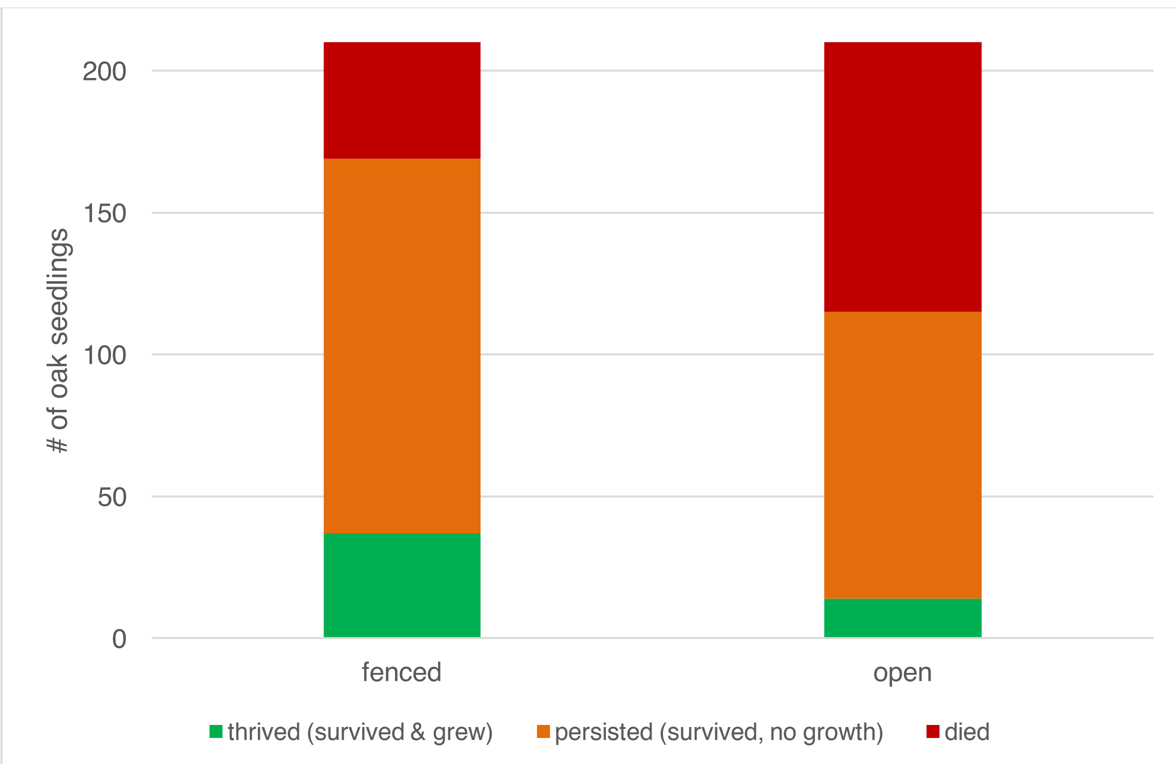
Analyses of whether initial condition was linked to the likelihood of browse damage, and whether browse intensity was correlated with higher mortality did not show clear patterns or significant chi-squared results, for several possible reasons: seedlings in poor initial condition may have been less likely to be browsed (vigorous plants are likely more nutritious and preferred by deer) but still likely to die; assessment of initial seedling condition during dormancy was difficult; and browse incidence (number of times browsed) may not fully indicate amount of browse damage on seedlings with varying branch patterns and diameters.

Unfenced seedlings were less likely to grow than fenced controls.

Of the oak seedlings that survived, some thrived and grew in height over the season, while others persisted with no change in height, and many died back (the height to living buds was lower at the end of the growing season than initial height when planted).[5]

Among survivors, unfenced seedlings were significantly less likely to grow than fenced seedlings: 12% of 115 surviving unfenced seedlings showed growth, while 22% of the 151 surviving fenced seedlings grew. A chi-squared analysis shows that this level is significant ($p<0.05$, $\chi^2=4.63$, d.f.=1), indicating there is a probability of less than 5% that this result occurred by random chance. In terms of proportion of all seedlings planted, 7% of unfenced seedlings grew, while 18% of fenced seedlings did.

Figure 12. Total number of 210 oak seedlings that died, persisted, and grew across all fenced and open (unfenced) plots. Seedlings that thrived were those that grew over the season; those that persisted either did not grow or partly died back.



[5] Height is not always the best indicator of growth but is the only measurement available for this study. Other measurements, such as change in biomass and diameter, were not practical and/or would not be meaningful given the variable initial seedling size. Height can increase more when plants are shaded—paradoxically, stems may elongate in shady conditions as plants attempt to grow toward light, even while lower resources lead to lower biomass gain—but shading was similar for paired plots, so it should not affect the overall comparison of height changes between open and fenced seedlings.

SUMMARY

This pilot experimental study, in which red oak seedlings were planted and monitored in 10 city parks (and in a separate study at the Arboretum), found that deer browsed a total of 61% of the oak seedlings, ranging from 20–90% across 11 sites—levels that exceed the 15% recommended in existing scientific literature as allowing for sustainable tree regeneration (Blossey 2014).

Although many studies in the literature have found that intense deer browsing can lead to declining forest regeneration levels, the 15% level proposed by Blossey (2014) is the only published figure to date that gives a specific number for the proportion of seedlings browsed per year that indicates that deer browse is too high to achieve tree regeneration. Waller (2016) notes that this is an area of active research and additional results will likely be published soon; he suggests that because site conditions vary, the acceptable level of browsing could be somewhat higher in some sites—but could be lower in others. However, the proportion of seedlings browsed by deer per year still serves as a useful metric for gauging whether deer management is resulting in less vegetation damage, and the accumulation of Ann Arbor data over time will allow us to understand browse impacts on tree regeneration in local sites.

Various mammals can damage tree seedlings, but deer did the most damage. Deer alone were responsible for 73% of the damage on the 151 unfenced seedlings that were browsed, with an additional 13% browsed by both deer and small mammals, for a total of 86% of browsed seedlings damaged by deer. A total of 9% of seedlings were browsed by small mammals only; including the seedlings also browsed by deer, 22% of seedlings showed evidence of small mammal browse.

Unfenced deer-accessible seedlings were significantly more likely to die than fenced controls protected from deer. For those seedlings that survived, unfenced seedlings were significantly less likely to grow in height than fenced controls.

Red oaks were chosen as experimental browse damage indicators because they are intermediate in browse preference. Thus, the levels documented here may not fully indicate the browse damage on more sensitive species, such as trilliums and other spring wildflowers. Trilliums are being assessed in a separate study established in 2016 for which preliminary data will be available in 2017.

RECOMMENDATIONS FOR FUTURE MONITORING

This pilot study demonstrated that experimental plantings of red oak seedlings offer a clear metric—proportion of seedlings browsed by deer—for gauging deer browse intensity. This protocol can be repeated annually to gauge how deer management efforts are affecting deer damage on vegetation.

Future studies could benefit from a few small modifications to the methods used in the pilot study. Four recommended changes include seedling source and initial condition; planting dates; and use of fenced experimental controls. In addition, more species could be monitored for a broader perspective on how deer are affecting diverse plants, including spring wildflowers and those of importance to pollinators.

Seedling source and initial condition: use 1–2 year-old container-grown seedlings
Due to timing of study approval and data needs, we used bare-root rather than container-grown seedlings for this pilot study because that was all that was available. In general, bare-root seedlings have lower transplant survival than container-grown seedlings, but it was difficult to assess seedling condition and transplant mortality during the winter dormant period. In addition, the bare-root seedlings in the 12–18" size class were highly variable in age, diameter, and form. Using first- or second-year container grown seedlings would offer more standard initial conditions and easily quantifiable browse damage amounts. First-year seedlings are shorter than the bare-root seedlings used in this pilot study (typically 4–8" rather than 12–18"), so they may be less likely to be discovered by deer, potentially leading to somewhat lower future browse levels compared to this pilot year. However, the Cornell study (Blossey 2014) used first-year seedlings in this size class.

Planting dates: consider planting in spring rather than winter.
During the pilot study, we planted seedlings during late November and December to ensure that data would be available by fall of 2016. However, transplant mortality could not be assessed while plants were dormant. Planting oak seedlings during spring (April or May) instead would allow for transplant mortality to be assessed. Seedling condition can be accurately assessed as soon as plants break dormancy and leaves emerge in May and June; seedlings that die or are in poor condition following transplanting (due to transplant shock rather than mammal damage) can be replaced within the first month. This would allow a clear analysis of connections between browse damage and mortality.

If seedlings are planted during the spring, a full year of monitoring would not be complete by the time deer management decisions are being made in the fall (October-November). However, analysis of the seasonal distribution of browse damage during this pilot year showed that most deer browsing at most parks occurred during the 2nd through 4th monitoring periods (April through September)—a total of 120 out of the 156 deer-browsed seedlings (77%) were first browsed during that time (Figure 9, above). Data for a shorter time period can be interpreted with this in mind.

Fenced experimental controls: not needed for future studies

This pilot study established that seedlings in fenced control plots had higher survival and growth than those in unfenced plots open to deer. However, the fences were costly and time-consuming, and did not fully protect seedlings from deer, effective control fences would have to be larger and costlier. The Cornell study (Blossey 2014) discontinued the use of fences after demonstrating the higher survival rates of fenced seedlings during the first year or two. Discontinuing the use of fences in future Ann Arbor studies would allow for planting more seedlings in more sites and focusing on the primary metric: proportion of seedlings browsed across sites.

To fully understand how deer management affects vegetation within and across the city's natural areas, more red oak seedlings could be planted and tracked at more locations within the larger parks (a need suggested by the differences within Bird Hills) and across more parks. In particular, Ward 4 should be represented in the survey, but was not because the major natural area within the ward (Pioneer Woods) belongs to the Ann Arbor Public Schools, rather than the city parks. A collaborative effort with the schools or Friends of Greenview could cover Pioneer Woods with the aim of understanding forest regeneration and furthering environmental education in areas where deer will not be managed—areas that can serve as a comparison for areas where deer populations are reduced.

Study species: Consider additional species beyond red oak seedlings.

This study focused on documenting current browse intensity with straightforward measurements in a clear, timely way. Because red oaks are of intermediate browse preference, they do not indicate damage to the most sensitive species. Future monitoring could be expanded to include more species and more sensitive species, such as trillium, either in experimental plantings or by using browse damage surveys on existing plants, to supplement the standard metric provided by red oaks. A preliminary study is underway to assess trillium in 4 parks, but this effort could be expanded to include an experimental approach with several species (e.g., wildflowers of importance to pollinators).

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