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FLORISTIC INVENTORY OF WOOLLEN'S GARDENS NATURE PRESERVE, INDIANAPOLIS, MARION COUNTY, INDIANA, USA, WITH QUANTITATIVE VEGETATION SAMPLING OF PERMANENT PLOTS IN 2003 AND 2016

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ABSTRACT. Urban forest fragments face challenges to habitat quality due to small size, isolation from larger natural areas, and close association with anthropogenic disturbance. Monitoring changes in vegetation can inform management practices targeted at preserving biodiversity in the face of these threats. Woollen's Gardens is a high-quality mesic upland forest preserve in the city of Indianapolis, Indiana, USA, with a beech-maple older-growth forest and a significant display of showy spring wildflowers. The entire preserve was inventoried and quantitative vegetation analysis along seven 100 m transects was conducted in 2003 and again in 2016 to track changes. Data from both years document a high-quality flora with few non-native plants. Floristic Quality Index values for native species, derived from Floristic Quality Assessment, were 50.2 in 2003 and 47.3 in 2016. Native mean C-values of 4.5 and 4.3 for each year support that the site is comparable to the highest quality natural areas in central Indiana. Values declined little when non-natives were included, indicating non-natives are having little negative impact on the flora. Although non-natives comprised less than 10% of the flora, 11 of the 16 species are considered invasive in Indiana. In 2003, invasive Amur honeysuckle (*Lonicera maackii*) was among species in plots with the highest relative importance value. In 2016, invasive wintercreeper (*Euonymus fortunei*) was among these species. Limited public access to Woollen's Gardens minimizes human disturbance, but invasive species are a threat to vegetation quality. Continuation of eradication efforts is strongly recommended before populations of these non-natives become more difficult to control.

Keywords: Floristic quality index (FQI), Indiana flora, invasive species, floristic change, urban forest fragment

INTRODUCTION

Studying changes in floristic composition of natural areas over time provides insight into vegetation quality that can be used to better understand plant community dynamics, to document species introductions and extirpations, and to inform site management. Quantitative vegetation sampling of permanent plots has the additional benefit of providing data on abundance and frequency, allowing floristic change to be more completely documented and monitored through time. Data derived from repeated sampling of permanent plots in locations where the surrounding landscape is undergoing significant habitat alteration, such as in cities, can provide important data for tracking the influences of urbanization on flora. For example, Dolan et al. (2015) documented an increase in the number and coverage of non-native species over a decade in two natural areas in Indianapolis, Indiana, based on permanent plot data.

Supported by funding from the Land Stewardship Office of the City of Indianapolis, we surveyed Woollen's Gardens, an urban forest fragment, in 2003 to get a base-line assessment of the plants present. In 2016, the study was repeated, visiting the preserve multiple times over the course of the year to record an overall inventory and resampling plots along the seven transects established in 2003. To report changes over time, herbaceous vegetation was quantified and overall floristic quality evaluated for both years. Results are reported here, along with management recommendations based on the findings.

Woollen's Gardens is a 38 acre state-dedicated Nature Preserve in northeast Marion County. The preserve is a remnant of a larger gift of land to the city by William Woollen in 1909 (Fig. 1). The land was used at that time for nature study. As a

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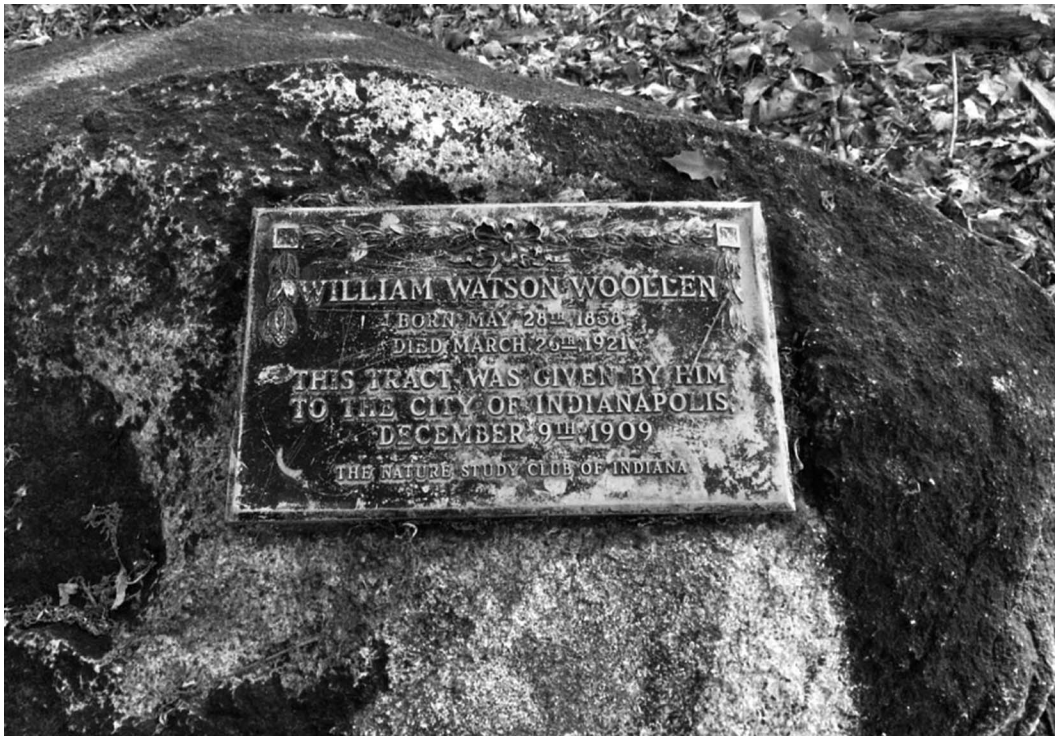

Figure 1.—Memorial plaque at Woollen's Gardens Nature Preserve.

city park, the site was spared from development. The site has been long-recognized as one of the highest-quality forested natural areas in the city (Brothers 1994). Dolan et al. (2011) documented Woollen's Gardens to be among the top three of 14 natural areas inventoried between 1996 and 2007 in Indianapolis, based on a low percentage of non-native plants and other measures of habitat integrity.

The Indiana Department of Natural Resources Directory of Indiana's Dedicated Nature Preserves, (IDNR 1988) describes Woollen's Gardens as "old-growth mesic upland forest dominated by beech, sugar maple, hackberry, red oak, chinquapin oak, black maple, and blue ash, with some trees reaching diameters of up to 40 inches." Indianapolis/Marion County is in the Central Till Plain Natural Region of Indiana (Homoya et al. 1985). This is a region of gently rolling terrain comprised of Wisconsin era glacial till deposits, often over 30 m deep. The area was 98% forested in pre-European settlement times (Barr et al. 2002).

Woollen's Gardens is bounded on the north and west by Fall Creek, on the east by Interstate 465, and on the south by apartments and an upscale neighborhood of estate-style single-family homes. The site is characterized by a floodplain adjacent to the creek and a series of north-facing ridges above the creek, separated by, in some cases, fairly deeply carved ravines (Fig. 2). The upland woodland is visually uniform with prominent mature trees. Areas of disturbance occur in flood-prone sites along the creek and adjacent to the apartment complex and yards. Dumping of trash and yard refuse, along with run-off sites of gray water, are present in these areas but the habitat is more pristine deeper in the preserve. Management has primarily been focused on invasive species removal.

MATERIALS AND METHODS

Floral inventory.—The preserve was visited 12 times from April to November during 2003 and 13 times during the same months in 2016. The flora was inventoried by meander walks that covered all areas of the preserve. Names follow usage from the Indiana Plant Atlas (Dolan & Moore 2017) and/or the online Universal FQA calculator (Freyman et al. 2015). Dr. Paul Rothrock of Indiana Univer-

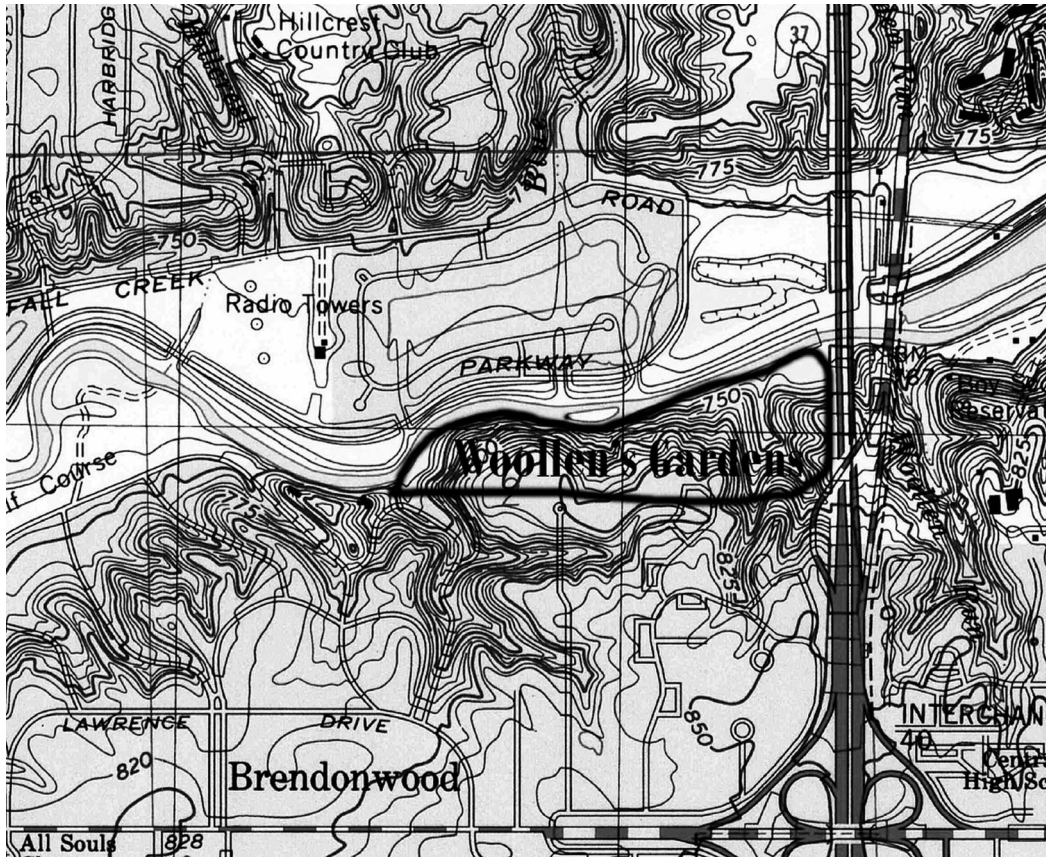

Figure 2.—Woollen's Gardens Nature Preserve topography and location. Note close proximity of major interstate highways and residential development.

sity's Deam Herbarium provided identification of grasses and sedges.

Floristic quality assessment.—Plant lists from both survey years were analyzed separately and combined using the Indiana database (based on Rothrock (2004)) of the Floristic Quality Assessment (FQA) software (Freyman et al. 2015). Mean C, a component of FQA, measures the overall quality of the habitat as indicated by the native species present (Swink & Wilhelm 1994). In this approach, native species have been assigned numbers, coefficients of conservatism (C-values), from 0–10 based on their perceived fidelity to natural plant communities. Higher numbers indicate intolerance of disturbance and restriction to presettlement remnants (Rothrock 2004). The C values are averaged to generate a mean C. In general, mean C of 3.5 and higher indicates that a community retains remnant natural quality. The Floristic Quality Index (FQI) for a site is calculated by multiplying the mean C-value for all native plants at a site by the square root of the number of native species present, thereby weighting the mean C-value by species richness. Higher FQI numbers indicate greater natural habitat integrity. Mean C and FQI with non-natives indicates the influence non-native plants have in reducing habitat quality. Sites with high natural area quality in central Indiana would be expected to have FQI values of 35 or greater (Rothrock & Homoya 2005). When comparing FQI values for a given site over time, the absolute value is not as important as how the number changes through time, with decreasing values indicating site quality decline from an ecological perspective.

Quantitative vegetation analysis.—Seven 100 m transects located throughout the preserve (Fig. 3) were assessed between May and August

Figure 3.—General locations of survey transects in Woollen's Gardens Nature Preserve. GPS coordinates are presented in Appendix 1.

in 2003 and 2016. Transect GPS coordinates and sample dates are presented in Appendix 1. Six of the seven transects were in upland forest habitat; the seventh was located on the floodplain of Fall Creek. Each species in the herb-layer (all herbaceous plants and woody plants smaller than 10 cm dbh) was identified and its aerial coverage in 1 m^2 plots located every 10 m along each transect was characterized. We used a modified Daubenmire cover class scheme (Daubenmire 1959; McCune & Grace 2002) to document cover: 1 = 1–7%, 2 = 8–25%, 3 = 26–50%, 4 = 51–75%, 5 = 76–93%, and 6 = 94–100%. Frequency (the number of plots out of 70 that each species occurred) and average cover class (averaged over all 70 plots) were calculated for herb-layer vegetation. Relative importance values (RIV) were calculated for each species by adding relative frequency and relative cover and dividing by two.

End points of the seven transects for vegetation sampling were marked temporarily in 2003 and their Global Positioning System (GPS) locations recorded. Prior to 2016 work, a professional survey team relocated the end points to within 1.0 cm accuracy using current GPS technology. These points were then marked with rebar pounded into the ground to within 2–5 cm of the soil surface.

RESULTS

A total of 166 taxa was observed during the two study years. Showy stands of declined trillium (*Trillium flexipes*) were present in 2003, along with pink valerian (*Valeriana pauciflora*) and starry campion (*Silene stellata*). In 2016, feathery false Solomon seal (*Maianthemum racemosum*) was especially prominent throughout the preserve. All plants are listed in Appendix 2, along with C-value, physiognomy (tree, fern, perennial forb, etc.), and the year and date first seen. Only 16 of the total taxa (9.6%) were non-native plants (indicated with name in capital letters in Appendix 2). The only rare, threatened, or endangered taxon found at Woollen's Gardens was American ginseng (*Panax quinquefolius*), seen in 2016. It is a state listed Watch List plant (http://www.in.gov/dnr/naturepreserve/files/np-etrplants.pdf). Cigar tree (*Catalpa speciosa)* is state listed in its native range near the Ohio River in southwestern

Table 1.—Floristic quality assessment results for Woollen's Gardens.

	Both years	2003	2016
NATIVE SPECIES	150	128	122
Total Species	166	139	134
% Native	90.4	92.1	91.0
NATIVE MEAN C	4.5	4.5	4.3
W/Non-native	4.0	4.1	3.9
NATIVE FQI	54.2	50.2	47.3
W/Non-Natives	51.5	48.0	45.1

Indiana, but in central Indiana it has escaped from cultivation (Jackson 2004). Downy yellow violet (*Viola pubescens*) is a Watch List plant, but that designation does not apply to the variety occurring in central Indiana (Michael Homoya, Pers. Comm.), and the FQA database for Indiana does not distinguish varieties for this species (Rothrock 2004).

Floristic Quality Assessment for Woollen's Gardens shows the presence of a flora with numerous conservative species that is minimally impacted by non-natives (Table 1). The reduction in mean C and mean FQI when non-natives are included is small for each sample year. Thirty-three species with C-values of 7 or greater were seen in one or both years (Table 2). C-values of 7–10 reflect species representative of high-quality natural areas that have suffered little disturbance (Swink & Wilhelm 1994). Smooth blue aster (*Symphyotrichum laeve*) was the only C-value 10 species. It was seen in 2003 but not 2016. Glade fern (*Diplazium pycnocarpon*), the only plant with a C-value of 9, was found both years. Comparison of plants with low C-values (C = 0–3) shows an increase in 2016 compared with 2003 (Fig. 4).

Herb-layer plot data.—Data on frequency and abundance of individual species collected from surveyed plots reveal additional changes in the flora between survey years (Appendix 3). The most striking difference between years is the RIV of 13.0 for Canada wood nettle (*Laportea canadensis*) in 2016. The species was not among the top ten species for RIV in 2003. RIV of sugar maple (*Acer saccharum* ssp. *saccharum*) almost doubled and RIV of ash seedlings (*Fraxinus* sp.) more than doubled between sample years. Two invasive species were among the top 10 in RIV: Amur honeysuckle (*Lonicera maackii*) in 2003 and wintercreeper (*Euonymus fortunei*) in 2016.

An average of four species was found in each plot in 2003; in 2016 the average was three. These numbers mask a species turnover rate of almost 50%. Forty species were present in plots in both 2003 and 2016. Seventeen were present only in 2003, 14 only in 2016.

Species of concern.—Although total site inventories for the two years documented few non-natives, over half that were present are invasive species of management concern in Indiana (https://www.entm.purdue.edu/iisc/invasiveplants.php). Nine of the 11 invasive species rank as species of high concern in the state (Table 3). Herb-layer data from the sample plots allow comparison of the abundance and location of invasives (Table 4). Transects 4, 6, and 7 harbored the most invasives. Transect 7 is located in the floodplain of Fall Creek (Fig. 3), a location subject to soil disturbance and spread of propagules due to flooding. Transects 4 and 6 are most closely adjacent to neighborhood edges (Fig. 3), points of increased likelihood of introduction and spread of invasives.

DISCUSSION

Data from both 2003 and 2016 document that Woollen's Gardens continues to be a high-quality example of upland forest, as first noted by Brothers (1994). Ninety percent of the species present are native to Indiana. The average for 14 Indianapolis/Marion County parks and natural areas reported by Dolan et al. (2011) is 81%, while the overall average for the flora of Indiana as a whole is estimated to be 70% (Kay Yatskievych, Pers. Comm). FQI values for Woollen's Gardens declined by 2.9 units, calculated based on either natives only or natives with non-natives included, between 2003 and 2016, indicating a slight decline in vegetation quality, even though the percentage of non-natives was similar both years. However, even the reduced FQI of 47.3 for 2016 indicates the flora of Woollen's Gardens is of regional significance from a conservation perspective (Swink & Wilhelm 1994).

FQI can be influenced by the size of an area being inventoried (Rothrock & Homoya 2005), so it is better used to detect changes in quality at a single site through time than to make comparisons between sites. Mean C-values are independent of the area of a site being inventoried, allowing direct comparisons between different sites. Native mean C-values for both years at Woollen's Gardens of greater than 4.0 are comparable to values we have found in the other state dedicated nature preserves in Marion County: Marott Park, Spring Pond,

Table 2.—Plants with C values of 7 or greater present at Woollen's Gardens.

Scientific name	Common name	C-value	Year observed	
			2003	2016
Symphyotrichum laeve	Smooth blue aster	10	x	
Diplazium pycnocarpon	Glade fern	9	x	x
Anemone acutiloba	Sharp-lobed hepatica	8	x	x
Carex amphibola	False gray sedge	8	x	
Carex hitchcockiana	Hairy gray sedge	8		x
Carex oligocarpa	Few-fruited gray sedge	8		x
Carya laciniosa	Big shellbark hickory	8	x	x
Caulophyllum thalictroides	Blue cohosh	8		x
Collinsonia canadensis	Citronella horse balm	8	x	x
Epifagus virginiana	Beech drops	8	x	
Fagus grandifolia	American beech	8	x	x
Hydrophyllum canadense	Canada waterleaf	8	x	x
Symplocarpus foetidus	Skunk cabbage	8	x	
Trillium grandiflorum	Large white trillium	8	x	
Actaea pachypoda	Doll's-eyes	7	x	x
Carex albursina	Blunt-scaled wood sedge	7		x
Carex laxiflora	Beech wood sedge	7	x	x
Dicentra canadensis	Squirrel corn	7		x
Euonymus obovata	Running strawberry bush	7	x	x
Fraxinus quadrangulata	Blue ash	7	x	x
Galium circaezans	Smooth wild licorice	7	x	
Hydrangea arborescens	Wild hydrangea	7	x	x
Hydrophyllum macrophyllum	Large-leaf waterleaf	7	x	x
Packera obovata	Round-leaved ragwort	7	x	
Panax quinquefolius	American ginseng	7		x
Quercus bicolor	Swamp white oak	7		x
Ranunculus hispidus	Rough buttercup	7	x	x
Silene virginica	Fire pink	7	x	x
Solidago caesia	Bluestem goldenrod	7	x	
Stellaria pubera	Great chickweed	7	x	x
Stylophorum diphyllum	Celandine poppy	7	x	x
Uvularia grandiflora	Large-flower bellwort	7	x	x
Valeriana pauciflora	Pink valerian	7	x	x

and Eagle's Crest, with mean native C-values of 3.8, 3.8, and 4.5, respectively (Dolan et al. 2011). These properties all had higher native mean C-values than 10 other parks and natural areas remnants surveyed, which had mean native C-values in the 3.0–3.7 range. Hubini et al. (2017) recently reported mean native C-values of 3.4 for Cooper-Skinner Woods, an urban forest remnant on the Ball State University campus in Delaware County in east central Indiana. Mean native C-values for the best natural sites in the Central Till Plain of central Indiana are in the low 4 range. This is due to a limited number of conservative species, reflecting the historic presence of few specialized habitats (Rothrock & Homoya 2005), likely further influenced by contemporary factors, including small size and isolation from larger tracts of natural habitat and the increased presence of introduced species that accompany habitat conversion for urbanization and agriculture (Hubini et al. 2017 and references therein).

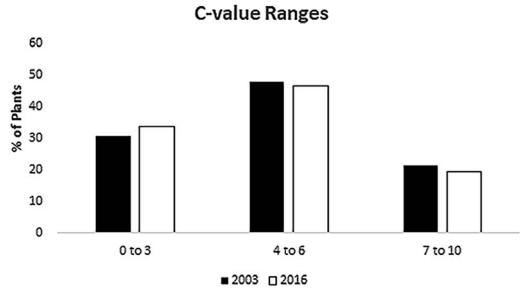

Figure 4.—Distribution of C-values for all native plants seen in 2003 and 2016.

Table 3.—Invasive species at Woollen's Gardens. Rank indicates invasiveness rank in Indiana (https://www.entm.purdue.edu/iisc/invasiveplants.php).

Scientific name	Common name	Year observed		Rank
		2003	2016	
Ailanthus altissima	Tree-of-heaven	x	x	high
Alliaria petiolata	Garlic mustard	x	x	high
Berberis thunbergii	Japanese barberry	x		high
Celastrus orbiculata	Oriental bittersweet	x	x	high
Euonymus fortunei	Wintercreeper	x	x	high
Ligustrum obtusifolium	Border privet	x	x	high
Lonicera japonica	Japanese honeysuckle	x		high
Lonicera maackii	Amur honeysuckle	x	x	high
Ranunculus ficaria	Lesser celandine	x	x	caution
Rhodotypos scandens	Jetbead	x	x	caution
Rosa multiflora	Japanese rose		x	high

Woollen's Gardens vegetation quality is not currently greatly influenced by non-native species, based on FQA. Using data from the 2003 inventory, Dolan et al. (2011) reported Woollen's Gardens had the highest mean C-value with non-natives of 14 natural areas in Indianapolis surveyed between 1996 and 2007. The 2016 mean C-value with non-natives of 3.9 is in line with these findings. Differences between mean C with and without non-natives each year was only 0.4 units. Rothrock & Homoya (2005) have suggested that the natural quality of a site has been compromised when non-native species richness lowers the mean C-value by more than 0.7 units.

Although about the same number of species was documented in sample plots in 2003 and 2016, these numbers mask a species turnover rate of almost 50%. This is a phenomenon seen at other sites in the city (Dolan et al. 2015) and has been attributed to a combination of factors, including disturbance caused by management to remove invasive species, white tail deer (*Odocoileus virginianus* Zimm) browse, and rainfall and other climatological differences between sample years (Dolan et al. 2015). Aspects of this species turnover are reflected in Figure 4 as an increase in species with lower C-values, those with lower fidelity to high-quality habitat.

Between 2003 and 2016, the RIV of sugar maple, ash seedlings, and Canada wood nettle greatly increased in the herb-layer at Woollen's Gardens. Increases in sugar maple over the last 20 years have been recently documented in other mesic forests in central Indiana (Dolan 2015) and were first reported in Indiana as early as 1977 (Abrell & Jackson 1977). This pattern has been seen in many regional oak-hickory forests, perhaps due to reduced frequency of natural disturbance such as fire (Pierce et al. 2006). Increases in the frequency and cover of ash seedlings may reflect natural mast cycles in ash (Boerner & Brinkman 1996) or increased seed produced by trees stressed by the recently introduced emerald ash borer (*Agrilus planipennis* Fairmaire), as has been proposed by BenDor et al. (2006). However, few or no ash seedlings were observed in forests in Ohio and Michigan with high ash mortality due to the borer (Klooster et al.

Table 4.—Invasive species present in herb-layer sample plots. Format = transect number: plot number (cover class). *Ranunculus ficaria* was present elsewhere in the preserve in 2003 but not detected in plots.

Species	2003	2016
Alliaria petiolata	T3:1(2), T3:7(3)	T2:1(1), T2:2(1), T2:4(1)
Euonymous fortunei	T3:7(3)	T3:1(2),T3:2(1),T3:3(2),T3:7(2)
		T4:4(1)
		T5:4(1)
		T6:1(1)
Lonicera maackii	T1:8(1)	T1:4(2),T1:6(1),T1:7(2)
	T3:5(3), T4:1(3),T4:4(2),T4:5(1), T6:4(3)	T3:4(1)
Ranunculus ficaria	–	T3:2(1), T3:10(2)

2014). Canada wood nettles are associated with gaps in forest canopy cover and have been documented to increase in forests where canopies have been opened due to Dutch elm disease (Biederman 2000), likely similar to gaps created when ash trees are killed by the borer. Further, dense patches of nettles are associated with reduced abundance of summer-reproducing forbs and graminoids in Minnesota forests, along with increases in sugar maple (Biederman 2000). Interactions of these disturbance factors with natural succession processes no doubt influence species dynamics at Woollen's Gardens.

The decline in RIV of Amur honeysuckle between survey years likely reflect management success at targeting this plant. However, wintercreeper has greatly increased in frequency and cover, a trend we have seen in many natural areas in Marion County over the last decade following honeysuckle removal. Not much is known about the invasion dynamics of wintercreeper (Bauer & Reynolds 2016; Mattingly et al. 2016), but increases in the presence of non-target invasive species are not uncommon following invasive species control efforts (Kettenring & Adams 2011). Wintercreeper should be a priority species for management action at Woollen's Gardens going forward.

Woollen's Gardens has little foot traffic due to limited parking, few trails, and lack of publicity. These features may contribute to the relatively low numbers of non-native and invasive plant species present, as hikers can introduce and spread non-native seed (Drayton & Primack 1996; Pickering et al. 2011). A large management concern at the site presented itself in September, 2016, however. Strong winds toppled many large trees along a ridge in the center of the preserve, near Transects 5 and 6. On our final visit in 2016, many leaning snapped trees and hanging branches presented hazards. This natural disturbance will open the canopy and potentially change the flora for many years to come. Forest openings are especially vulnerable to invasive species (Hutchinson & Vankat 1997; Pavlovic & Leicht-Young 2011), including wintercreeper (Swearingen & Bargeron 2016), which may then increase in density and/or spread within Woollen's Gardens. Management should focus on controlling invasives throughout the preserve, but especially in these areas. Vegetation should be reinventoried and transects surveyed again within the next few years to monitor changes in order to document the effectiveness of control efforts in maintaining habitat quality in this ecologically significant urban forest remnant.

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Appendix 1.—GPS coordinates for end points of transects and location of memorial plaque at Woollen's Gardens, with dates of sampling in 2003 and 2016.

Transect end point	X1	Y1	2003	2006
1a	-86.04865671640	39.86393599340	24 Jul	8 Aug
1b	-86.04811417650	39.86316989180		
2a	-86.05025729250	39.86363636590	25 May	26 May
2b	-86.05081993290	39.86286426150		
3a	-86.05114790570	39.86350318840	7 Jul	29 Jun
3b	-86.05124470330	39.86263547360		
4a	-86.04948316780	39.86275964190	7 Jul	26 Jun
4b	-86.05033173180	39.86220121890		
5a	-86.05411402700	39.86257418400	13 Aug	23 Aug
5b	-86.05298449660	39.86264173070		
6a	-86.05505816670	39.86273692250	2 Jun	25 May
6b	-86.05623313780	39.86254304350		
7a	-86.05762127820	39.86255656880	2 Jun	25 May
7b	-86.05713143170	39.86334260710		
Rock with plaque	-86.04974553940	39.86255893270		

Appendix 2.—All plants observed at Woollen's Gardens. Non-native species are in capital letters. * = invasive in Indiana. Miller = observed by Don Miller.

Scientific name	Common name	C	Physiognomy	2003	2016
Acer negundo	Boxelder	1	Tree	30 Apr	12 May
Acer rubrum	Red maple	5	Tree	27 May	
Acer saccharinum	Silver maple	1	Tree	12 May	26 May
Acer saccharum s. *nigrum*	Black maple	6	Tree	23 Apr	25 May
Acer saccharum s. *saccharum*	Sugar maple	4	Tree	23 Apr	12 May
Actaea pachypoda	Doll's-eyes	7	Perennial forb	30 Apr	26 May
Aesculus glabra	Ohio buckeye	5	Tree	23 Apr	19 Apr
Ageratina altissima	White snakeroot	2	Perennial forb	12 May	25 May
*AILANTHUS ALTISSIMA**	Tree-of-heaven	0	Tree	8 Sep	1 Jun
*ALLIARIA PETIOLATA**	Garlic mustard	0	Biennial forb	30 Apr	21 Mar
Allium tricoccum v. *burdickii*	Wild leek	6	Perennial forb	23 Apr	19 Apr
Anemone acutiloba	Sharp-lobed hepatica	8	Perennial forb	30 Apr	21 Mar
Arisaema dracontium	Green dragon	5	Perennial forb		25 May
Arisaema triphyllum	Indian turnip	4	Perennial forb	23 Apr	19 Apr
Arnoglossum atriplicifolium	Pale Indian plantain	6	Perennial forb	24 Jul	
Asarum canadense	Canada wild ginger	5	Perennial forb	23 Apr	19 Apr
Asimina triloba	Pawpaw	6	Tree	23 Apr	12 May
*BERBERIS THUNBERGII**	Japanese barberry	0	Shrub	27 May	
Bidens frondosa	Common beggar's ticks	1	Annual forb		23 Aug
Boehmeria cylindrica	False nettle	3	Perennial forb	2 Jun	
Cardamine concatenata	Toothwort	4	Perennial forb	23 Apr	21 Mar
Carex albursina	Blunt-scaled wood sedge	7	Perennial sedge		7 Jul
Carex amphibola	False gray sedge	8	Perennial sedge	12 May	
Carex gracilescens	Slender wood sedge	5	Perennial sedge		7 Jul
Carex grayi	Common bur sedge	5	Perennial sedge	27 May	23 Aug
Carex hitchcockiana	Hairy gray sedge	8	Perennial sedge		14 Jul
Carex jamesii	Grass sedge	4	Perennial sedge		7 Jul
Carex laxiflora	Beech wood sedge	7	Perennial sedge	30 Apr	29 Jun
Carex oligocarpa	Few-fruited gray sedge	8	Perennial sedge		1 Jun
Carpinus caroliniana	Blue beech	5	Tree	30 Apr	
Carya cordiformis	Bitternut hickory	5	Tree	30 Apr	1 Jun
Carya glabra	Pignut hickory	4	Tree	7 Jul	23 Aug
Carya laciniosa	Big shellbark hickory	8	Tree	27 May	1 Jun
Carya ovata	Shagbark hickory	4	Tree	7 Jul	1 Jun
Catalpa speciosa	Cigar tree	0	Tree		1 Jun
Caulophyllum thalictroides	Blue cohosh	8	Perennial forb		12 May
*CELASTRUS ORBICULATA**	Oriental bittersweet	0	Woody vine	30 Apr	1 Jun
Celtis occidentalis	Hackberry	3	Tree	30 Apr	25 May
Cercis canadensis	Eastern redbud	3	Tree	23 Apr	19 Apr
Claytonia virginica	Spring beauty	2	Perennial forb	7 Jul	
Circaea lutetiana	Enchanter's nightshade	2	Perennial forb	23 Apr	21 Mar
Collinsonia canadensis	Citronella horse balm	8	Perennial forb	13 Aug	19 May
Cornus florida	Flowering dogwood	4	Tree	23 Apr	
Cornus racemosa	Gray dogwood	2	Shrub	30 Apr	26 May
Crataegus sp.	Hawthorn	?	Tree	30 Apr	
Cryptotaenia canadensis	Honewort	3	Perennial forb	12 May	1 Jun
Cystopteris protrusa	Common fragile fern	4	Fern	30 Apr	19 Apr
Delphinium tricorne	Dwarf larkspur	5	Perennial forb	30 Apr	
Dicentra canadensis	Squirrel corn	7	Perennial forb		12 May
Dicentra cucullaria	Dutchman's breeches	6	Perennial forb	23 Apr	19 Apr
Diplazium pycnocarpon	Glade fern	9	Fern	12 May	12 May
DUCHESNEA INDICA	Indian strawberry	0	Perennial forb	23 Apr	
Elymus villosus	Hairy wild rye	4	Perennial forb	8 Sep	1 Jun
Elymus virginicus	Virginia wild rye	3	Perennial forb	12 May	1 Jun
Enemion biternatum	False rue anemone	5	Perennial forb	30 Apr	21 Mar

Appendix 2.—Continued.

Scientific name	Common name	C	Physiognomy	2003	2016
Epifagus virginiana	Beech drops	8	Perennial forb	8 Sep	
Erigenia bulbosa	Harbinger-of-spring	5	Perennial forb	23 Apr	21 Mar
Erigeron philadelphicus	Marsh fleabane	3	Perennial forb		1 Jun
Erythronium americanum	Yellow adder's tongue	5	Perennial forb	23 Apr	21 Mar
*EUONYMUS FORTUNEI**	Wintercreeper	0	Shrub	27 May	12 May
Euonymus obovata	Running strawberry bush	7	Shrub	12 May	19 May
Fagus grandifolia	American beech	8	Tree	23 Apr	21 Mar
Festuca subverticillata	Nodding fescue	2	Perennial grass		1 Jun
Floerkea proserpinacoides	False mermaid weed	5	Annual forb	30 Apr	
FORSYTHIA SUSPENSA	Weeping forsythia	0	Shrub		21 Mar
Fraxinus americana	White ash	4	Tree	23 Apr	26 May
Fraxinus pennsylvanica	Green ash	3	Tree	30 Apr	25 May
Fraxinus quadrangulata	Blue ash	7	Tree	30 Apr	19 May
Galium aparine	Annual bedstraw	1	Annual forb	30 Apr	19 May
Galium circaezans	Smooth wild licorice	7	Perennial forb	30 Apr	
Geranium maculatum	Wild geranium	4	Perennial forb	23 Apr	19 May
Geum canadense	White avens	1	Perennial forb	12 May	23 Aug
Glyceria striata	Fowl manna grass	4	Perennial forb	8 Sep	Miller
Hybanthus concolor	Green violet	6	Perennial forb	12 May	
Hydrangea arborescens	Wild hydrangea	7	Shrub	12 May	1 Jun
Hydrophyllum appendiculatum	Great waterleaf	6	Perennial forb	23-Apr	12-May
Hydrophyllum canadense	Canada waterleaf	8	Perennial forb	12 May	12 May
Hydrophyllum macrophyllum	Large-leaf waterleaf	7	Perennial forb	30 Apr	21 Apr
Hydrophyllum virginianum	Virginia waterleaf	4	Perennial forb	27 May	
Impatiens pallida	Pale touch-me-not	4	Annual forb	30 Apr	25 May
Iodanthus pinnatifidus	Violet cress	6	Perennial forb	12 May	12 May
Juglans nigra	Black walnut	2	Tree	30 Apr	23 Aug
Laportea canadensis	Canada wood nettle	2	Perennial forb	12 May	12 May
Lepidium virginicum	Common pepper grass	0	Annual forb		1 Jun
*LIGUSTRUM OBTUSIFOLIUM**	Border privet	0	Shrub	23 Apr	21 Mar
Lindera benzoin	Hairy spicebush	5	Shrub	30 Apr	19 Apr
Liriodendron tulipifera	Tulip poplar	4	Tree	30 Apr	12 May
*LONICERA JAPONICA**	Japanese honeysuckle	0	Woody vine	30 Apr	
*LONICERA MAACKII**	Amur honeysuckle	0	Shrub	23 Apr	12 May
Lysimachia ciliata	Fringed loosestrife	4	Perennial forb		23 Aug
LYSIMACHIA NUMMULARIA	Moneywort	0	Perennial forb		23 Aug
Maianthemum racemosum	Feathery false Solomon seal	4	Perennial forb	30 Apr	19 Apr
Maianthemum stellatum	Starry false Solomon seal	6	Perennial forb		12 May
Menispermum canadense	Moonseed	3	Woody vine	30 Apr	
Mertensia virginica	Virginia bluebells	6	Perennial forb	23 Apr	
Mimulus alatus	Winged monkey flower	4	Perennial forb		23 Aug
Nyssa sylvatica	Black gum	5	Tree		25 May
ORNITHOGALUM UMBELLATUM	Star-of-Bethlehem	0	Perennial forb		12 May
Osmorhiza claytonii	Hairy sweet cicely	3	Perennial forb	2 Jun	19 May
Osmorhiza longistylis	Anise root	3	Perennial forb	30 Apr	19 May
Ostrya virginiana	Hop hornbeam	5	Tree	2 Jun	12 May
Packera glabella	Butterweed	0	Annual forb		19 May
Packera obovata	Round-leaved ragwort	7	Perennial forb	30 Apr	
Panax quinquefolius	American ginseng	7	Perennial forb		Miller
Parthenocissus quinquefolia	Virginia creeper	2	Woody vine	30 Apr	12 May
Phlox divaricata	Blue phlox	5	Perennial forb	7 Jul	7 Jul
Phytolacca americana	Pokeweed	0	Perennial forb	23 Apr	19 Apr
Pilea pumila	Canada clearweed	2	Annual forb	12 May	19 May
Platanus occidentalis	Sycamore	3	Tree	30 Apr	25 May
Poa sylvestris	Woodland blue grass	5	Perennial forb	12 May	25 May
Podophyllum peltatum	May apple	3	Perennial forb	23 Apr	12 May

Appendix 2.—Continued.

Scientific name	Common name	C	Physiognomy	2003	2016
Polygonatum biflorum	Small solomon's seal	4	Perennial forb	30 Apr	25 May
Polymnia canadensis	Pale leafcup	3	Perennial forb	30 Apr	23 Aug
Polystichum acrostichoides	Christmas fern	5	Fern	30 Apr	19 May
Populus deltoides	Eastern cottonwood	1	Tree	12 May	25 May
Prenanthes alba	Lion's foot	5	Perennial forb	30 Apr	
Prunus serotina	Wild black cherry	1	Tree	30 Apr	12 May
Ptelea trifoliata	Smooth wafer ash	4	Shrub	8 Sep	1 Jun
Quercus alba	White oak	5	Tree	30 Apr	12 May
Quercus bicolor	Swamp white oak	7	Tree		25 May
Quercus muehlenbergii	Chinquapin oak	4	Tree	7 Jul	1 Jun
Quercus rubra	Northern red oak	4	Tree	30 Apr	19 May
Ranunculus abortivus	Little-leaf buttercup	0	Annual forb	23 Apr	
*RANUNCULUS FICARIA**	Lesser celandine	0	Perennial forb	23 Apr	21 Mar
Ranunculus hispidus	Rough buttercup	7	Perennial forb	30 Apr	12 May
*RHODOTYPOS SCANDENS**	Jetbead	0	Shrub	12 May	19 Apr
Ribes cynosbati	Prickly wild gooseberry	4	Shrub	30 Apr	12 May
*ROSA MULTIFLORA**	Japanese rose	0	Shrub		19 May
Rubus allegheniensis	Common blackberry	2	Shrub	22 Oct	1 Jun
Rudbeckia laciniata	Wild golden glow	3	Perennial forb	2 Jun	1 Jun
Sambucus nigra s. *canadensis*	Common elderberry	2	Shrub	12 May	12 May
Sanguinaria canadensis	Bloodroot	5	Perennial forb	23 Apr	21 Mar
Sanicula odorata	Black snakeroot	2	Perennial forb	23 Apr	21 Mar
Silene stellata	Starry campion	5	Perennial forb	24 Jul	
Silene virginica	Fire pink	7	Perennial forb	30 Apr	Miller
Smilax hispida (= *S. tamnoides*)	Bristly green brier	3	Woody vine	7 Jul	
Smilax herbacea (= *S. lasioneura*)	Cat brier	4	Herbaceous vine	12 May	25 May
Solidago caesia	Bluestem goldenrod	7	Perennial forb	24 Jul	
Solidago canadensis	Canada goldenrod	0	Perennial forb		1 Jun
Solidago flexicaulis	Zig-zag goldenrod	3	Perennial forb	24 Jul	14 Sep
Stachys palustris	Hedge-nettle	4	Perennial forb	27 May	
Stellaria pubera	Great chickweed	7	Perennial forb	23 Apr	19 May
Stylophorum diphyllum	Celandine poppy	7	Perennial forb	23 Apr	19 Apr
Symphyotrichum cordifolium	Heart-leaved aster	5	Perennial forb	27 May	8 Nov
Symphyotrichum laeve	Smooth blue aster	10	Perennial forb	22 Oct	
Symphyotrichum lateriflorum	Side-flowering aster	3	Perennial forb	22 Oct	
Symphyotrichum pilosum	Hairy aster	0	Perennial forb	22 Oct	
Symplocarpus foetidus	Skunk cabbage	8	Perennial forb	22 Oct	
TARAXACUM OFFICINALE	Common dandelion	0	Perennial forb		1 Jun
Tilia americana	American linden	5	Tree	30 Apr	23 Aug
Tovara virginiana	Virginia knotweed	3	Perennial forb	30 Apr	25 May
Toxicodendron radicans	Poison ivy	1	Woody vine	23 Apr	19 May
Tradescantia subaspera	Broad-leaved spiderwort	4	Perennial forb	24 Jul	23 Aug
Trillium flexipes	Declined trillium	5	Perennial forb	23 Apr	12 May
Trillium grandiflorum	Large white trillium	8	Perennial forb	23 Apr	
Trillium recurvatum	Red trillium	4	Perennial forb	30 Apr	21 Mar
Trillium sessile	Sessile trillium	4	Perennial forb	30 Apr	21 Mar
Ulmus americana	American elm	3	Tree	2 Jun	25 May
Ulmus rubra	Slippery elm	3	Tree	30 Apr	25 May
Uvularia grandiflora	Large-flower bellwort	7	Perennial forb	23 Apr	21 Mar
Valeriana pauciflora	Pink valerian	7	Perennial forb	12 May	19 May
Verbena urticifolia	White vervain	3	Perennial forb		14 Sep
Verbesina alternifolia	Wingstem	3	Perennial forb	12 May	
Viola pubescens	Downy yellow violet	5	Perennial forb	30 Apr	19 Apr
Viola sororia	Woolly blue violet	1	Perennial forb	23 Apr	19 Apr
Viola striata	Common white violet	4	Perennial forb	30 Apr	12 May

Appendix 3.—Frequency, average cover class, and relative importance value (RIV) for herb-layer species in transects. RIV was calculated by adding each species' relative frequency and relative cover and dividing by two. Only absolute values for frequency and cover are presented here. Taxa with the ten greatest RIVs each year are in bold.

	2003			2016		
Species	Freq	Ave cover	RIV	Freq	Ave cover	RIV
Acer negundo	-	-	-	3	0.06	1.3
Acer saccharinum	6	0.09	1.8	-	-	-
Acer saccharum s. *nigrum*	-	-	-	1	0.03	0.5
Acer saccharum* s. *saccharum	**15**	**0.31**	**5.4**	**27**	**0.46**	**10.7**
Actaea pachypoda	3	0.06	1.0	1	0.03	0.5
Aesculus glabra	3	0.10	1.4	1	0.03	0.5
Ageratina altissima	-	-	-	1	0.03	0.5
Alliaria petiolata	2	0.04	0.7	3	0.04	1.1
Allium tricoccum v. *burdickii*	7	0.11	2.3	3	0.04	1.1
Anemone acutiloba	5	0.08	1.7	2	0.03	0.8
Arisaema dracontium	-	-	-	2	0.04	0.9
Arisaema triphyllum	5	0.09	1.6	2	0.04	0.9
Asarum canadense	**14**	**0.36**	**5.6**	**13**	**0.37**	**6.7**
Asimina triloba	3	0.10	1.4	1	0.06	0.8
Boehmeria cylindrica	2	0.07	1.0	-	-	-
Cardamine concatenata	-	-	-	3	0.04	1.1
Carex laxiflora	6	0.09	1.8	3	0.06	1.3
Carex sp.	-	-	-	2	0.04	0.9
Carya seedling	5	0.10	1.8	3	0.04	1.1
Celtis occidentalis	2	0.03	0.6	1	0.01	0.4
Cornus seedling	-	-	-	1	0.03	0.5
Cryptotaenia canadensis	1	0.01	0.3	-	-	-
Cystopteris protrusa	2	0.03	0.6	-	-	-
Elymus virginicus	1	0.01	0.3	-	-	-
Enemion biternatum	6	0.10	2.0	2	0.03	0.8
Euonymus fortunei	1	0.04	0.6	**7**	**0.14**	**3.0**
Euonymus obovata	-	-	-	1	0.03	0.5
***Fraxinus* seedling**	**8**	**0.24**	**3.5**	**17**	**0.37**	**7.6**
Galium aparine	3	0.04	0.9	1	0.01	0.4
Geum canadense	2	0.03	0.6	1	0.01	0.4
Hydrangea arborescens	1	0.04	0.6	-	-	-
Hydrophyllum appendiculatum	6	0.09	1.8	3	0.06	1.3
Hydrophyllum canadense	**7**	**0.34**	**4.2**	**5**	**0.19**	**3.0**
Hydrophyllum macrophyllum	**9**	**0.20**	**3.3**	1	0.01	0.4
Impatiens pallida	**15**	**0.30**	**5.3**	2	0.03	0.8
Laportea canadensis	3	0.11	1.5	**23**	**0.77**	**13.0**
Lindera benzoin	6	0.17	2.5	1	0.01	0.4
Liriodendron tulipifera	-	-	-	1	0.01	0.4
Lonicera maackii	**6**	**0.19**	**2.7**	4	0.09	1.8
Maianthemum racemosum	**16**	**0.41**	**6.4**	**11**	**0.27**	**5.2**
Osmorhiza claytonii	1	0.01	0.3	-	-	-
Osmorhiza longistylis	1	0.01	0.3	-	-	-
Parthenocissus quinquefolia	**12**	**0.30**	**4.7**	**10**	**0.20**	**4.3**
Phlox divaricata	-	-	-	2	0.03	0.8
Pilea pumila	-	-	-	7	0.10	2.6
Podophyllum peltatum	5	0.14	2.1	3	0.09	1.6
Polygonatum biflorum	**13**	**0.26**	**4.6**	**10**	**0.24**	**4.7**
Polymnia canadensis	-	-	-	1	0.01	0.4
Polystichum acrostichoides	1	0.03	0.5	-	-	-
Prunus serotina	4	0.06	1.2	7	0.10	2.6
Quercus seedling	7	0.10	2.2	2	0.03	0.8

Appendix 3.—Continued.

	2003			2016		
Species	Freq	Ave cover	RIV	Freq	Ave cover	RIV
Ranunculus abortivus	3	0.04	0.9	-	-	-
Ranunculus ficaria	-	-	-	2	0.04	0.9
Ribes cynosbati	1	0.03	0.5	-	-	-
Rudbeckia laciniata	1	0.03	0.5	-	-	-
Sanguinaria canadensis	5	0.10	1.8	5	0.07	1.9
Sanicula odorata	5	0.06	1.7	1	0.03	0.5
Smilax hispida	-	-	-	2	0.03	0.8
Smilax lasioneura	1	0.01	0.3	-	-	-
Solidago caesia	1	0.03	0.5	-	-	-
Solidago flexicaulis	4	0.09	1.5	1	0.01	0.4
Stylophorum diphyllum	3	0.04	0.9	1	0.01	0.4
Symphyotrichum cordifolium	6	0.10	2.0	-	-	-
Tovara virginiana	4	0.07	1.4	2	0.03	0.8
Toxicodendron radicans	5	0.14	2.1	**7**	**0.13**	**2.9**
Tradescantia subaspera	1	0.03	0.5	1	0.01	0.4
Trillium sessile	2	0.03	0.6	-	-	-
Ulmus seedling	3	0.07	1.2	3	0.04	1.1
Uvularia grandiflora	3	0.06	1.0	3	0.04	1.1
Verbesina alternifolia	1	0.01	0.3	-	-	-
Viola sp.	6	0.13	2.2	4	0.06	1.5