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Living *More Than Just Enough* for the City: Persistence of High-Quality Vegetation in Natural Areas in an Urban Setting

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Abstract: Urban environments pose special challenges to flora, including altered disturbance regimes, habitat fragmentation, and increased opportunity for invasion by non-native species. In addition, urban natural area represents most people's contact with nature, given the majority of the world's population currently live in cities. We used coefficients of conservatism (C-values), a system that ranks species based on perceived fidelity to remnant native plant communities that retain ecological integrity, to quantify habitat quality of 14 sites covering 850 ha within the city of Indianapolis, Indiana, in the Midwestern United States. All sites contained significant natural area and were inventoried via intensive complete censuses throughout one or two growing seasons within the last 15 years. Mean C-values for five sites were high, especially when compared to values reported for the highest quality preserves in central Indiana. However, for most sites the difference in mean C-value with and without non-natives was rather high, meaning that natural quality is likely to have been compromised by the presence of non-natives. Sites receiving the highest levels of stewardship and those with the least public access *via* trails had the highest mean native C-values. A total of 34 invasive non-native species were found across all 14 sites. Most were woody species. Mean C-value over all sites was significantly negatively correlated with the number of non-natives present, especially those considered invasive. These results demonstrate for the Indianapolis area, and likely other urbanized

Midwestern cities, remnant natural areas can retain high ecological value, especially if they receive regular environmental stewardship.

Keywords: biodiversity; biological invasions; urban ecology; urban conservation; urban flora; American Midwest; conservation coefficients

1. Introduction

Urbanization presents unique challenges to flora and fauna: it fosters special disturbance regimes [1,2], distinct soils [3] and biogeochemistry [4], and a higher proportion of introduced species [5,6] that distinguish urban habitats from more natural sites. It creates habitat loss directly through conversion during development and incrementally through time *via* fragmentation and isolation of remnants [7]. For plants, urban environments can lead to local extinction due to the cumulative effects of these factors [8]. Since habit alteration is likely to be more permanent in urban areas than in agricultural or peri-urban environments [9], species loss is more likely to be permanent.

For these reasons, people do not often associate urbanization with natural areas, but remnants of less-disturbed native vegetation can be found in most cities. These areas can host significant biodiversity, at levels of organization from the species [10,11] to the community [2,9], and can provide habitat for sustainable populations of rare species [12]. Natural vegetation provides a host of ecological services, including filtering of pollutants from air and water, decreased storm water run-off, and cooling of heat islands [13]. In addition, urban natural areas aid in improving the quality of human interaction with nature as they may provide most, if not all, of people's contact with nature.

Unfortunately, urban ecosystems and their natural areas are under constant threat as infrastructure growth continues. For example, land conversion in the United States towards urban and built-up areas rose 34% between 1982 and 1997 [14] to harbor an additional 50 million people during roughly the same time period [15]. This trend is expected to continue with future land devoted to developed area in the United States projected to increase 79% by 2025 [16]. Therefore, qualitative and quantitative assessments of remaining natural areas are needed not only to identify and protect unique habitats from development, but because they provide city planners and land managers with documentation of ecological assets, thereby optimizing the opportunity for provisioning of ecological services.

In this study, we present results from over a decade of inventory work in 14 natural areas within Indianapolis/Marion County, Indiana, a major metropolitan area of the American Midwest. Our goal is to (1) document the quality of flora, (2) identify invasive species that pose management concerns and (3) assess the usefulness of coefficients of conservatism (C-values) in identifying natural areas with high-quality vegetation to better inform conservation practices by ecological restorationists, land managers, city planners and others charged with preserving urban natural areas. To our knowledge, C-values have not been used to assess terrestrial urban natural areas.

2. Experimental Methods

2.1. Marion County Background

Marion County is located in central Indiana, in the Central Till Plain Section of the Central Till Plain Natural Region [17]. This region is predominated by neutral silt and silty clay loams of the Crosby-Brookston Association. Official government land surveys from 1820–1822 and soil survey records indicate that Marion County was 98% forested in pre-European settlement times [18] (for more information on historical land surveys in Indiana see [19]), with remaining land cover being open water or prairie. Specifically, mesic beech-maple covered 76% of the county, growing over an undissected plain of Wisconsin glacial till with small areas of oak-hickory forest on drier ridges. Northern flatwood communities were found on poorer draining sites, with red maple (*Acer rubrum*), pin oak (*Quercus palustris*), swamp white oak (*Q. bicolor*) and green ash (*Fraxinus pennsylvanica*) dominating. While in better-drained sites (including slopes around streams), American beech (*Fagus grandifolia*), sugar maple (*Acer saccharum*), black maple (*A. nigrum*), white oak (*Quercus alba*), red oak (*Q. rubra*), tulip poplar (*Liriodendron tulipifera*), black walnut (*Juglans nigra*), and white ash (*Fraxinus americana*) were found. Wet-mesic depressional forests were scattered throughout the county with floodplain forests along major rivers and tributaries. Wetlands including ponds, bog, marsh, and fens are estimated to have made up approximately 1% of the original land cover [18]. Most of the region has been greatly disturbed, primarily by ditching and draining of wetter sites, and clearing of forest for row crop agriculture. Barr *et al.* [18] report recent forest cover in Marion County has been reduced to 13%.

2.2. Inventory Methods and Site Descriptions

We inventoried the flora of 14 sites covering ca. 850 ha around the city of Indianapolis in Marion County (Table 1, Figure 1). Complete censuses were conducted by meander walks through entire sites to record all species present. Sites were visited a minimum of every other week throughout one or two growing seasons (March–November) (Table 1). Voucher specimens collected at Cold Spring School (CSS), Eagle Creek Nature Center (ECNC), Fort Harrison State Park (FHSP) and Juan Solomon Park (JSP) were deposited in the Friesner Herbarium of Butler University (BUT). We also present data from two other natural areas in the city that were similarly inventoried by other botanists (Table 1). All 14 sample sites have significant natural area remaining with remnants of older growth forest, but current and historical levels of disturbance varied among sites (see Supplement 1).

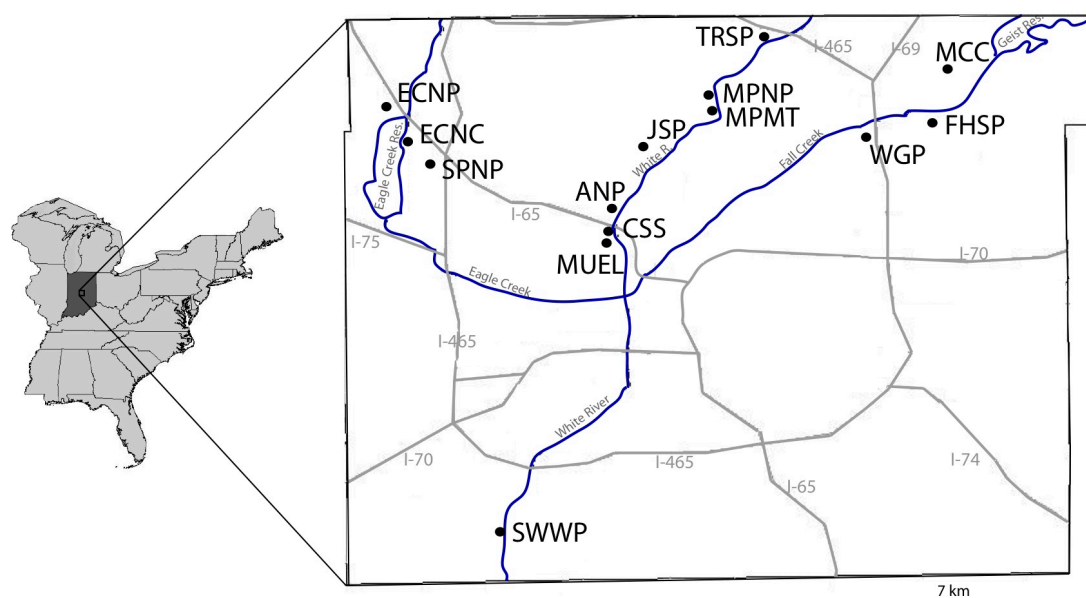
Three sites, Marrott Park (MPNP), Spring Pond (SPNP) and Eagle's Crest (ECNP), are state-dedicated nature preserves within larger parks owned and managed by the City of Indianapolis Department of Parks and Recreation ("Indy Parks"). These nature preserve sites are entirely older growth and receive management, including efforts to control invasive species, by the Stewardship Office of Indy Parks with occasional additional support from the Indiana Department of Natural Resources Division of Nature Preserves, a state agency. There are also restrictions on use and disturbance in these and all state preserves.

Table 1. Recent inventories of natural areas in Marion County, Indiana, U.S.A. Inventories conducted by Butler University staff and students unless otherwise indicated. Vouchers are housed in the Friesner Herbarium at Butler (BUT).

Site	Abbreviation	Year(s) Inventoried	Ha
Art and Nature Park	ANP	2001, 2005	24
Cold Spring School Campus	CSS	2004	16
Eagle Creek Park Nature Center	ECNC	1998	8
Eagle's Crest State Nature Preserve	ECNP	1997, 2007	120
Fort Harrison State Park *	FHSP	2006	506
Juan Solomon Park	JSP	1996	19
Marian University Ecolab **	MUEL	2001	22
Marott Park State Nature Preserve	MPNP	1999	8
Marott Park/Monon Trail	MPMT	2002	20
Mud Creek Conservancy	MCC	2004	9
Southwestways Park **	SWWP	1998, 2004	36
Spring Pond State Nature Preserve	SPNP	1996, 2007	18
Town Run South Park	TRSP	2003	28
Woollen's Garden Park	WGP	2003	15

* inventoried by Perry Scott for the Indianapolis Zoo. ** inventoried by Kevin Tunesvick, Spence Restoration Nursery (swale habitat at SWWP)

Figure 1. Study site locations within Marion County, Indiana, USA. Major waterways are indicated in blue. Abbreviations correspond to text in Table 1.



Additionally, six of our study sites are Indianapolis city parks without state nature preserve designation: ECNC, JSP, Marrott Park/Monon Trail (MPMT), Southwestways Park (SWWP), Township Run South Park (TRSP) and Woollen's Gardens Park (WGP). Surveys of all sites, except WGP, included some disturbed and open non-wooded areas. Contrastingly, WGP is entirely wooded and has no public access point. ECNC was located near the Eagle Creek Park Nature Center at the time

of our study (the Nature Center has relocated to a new site) and received stewardship attention from park naturalists and volunteers.

The remaining sites (*i.e.*, Art and Nature Park site (ANP), Ecolab (MUEL), CSS, Mud Creek Conservancy (MCC), FHSP) are owned and managed by various groups (see Supplement 1).

2.3. Data Analysis

Coefficients of conservatism (C-values), values based on species' perceived fidelity to remnant native plant communities that retain ecological integrity (hereafter referred to as high-quality habitats), were assigned based on Rothrock's [20] treatment for Indiana flora and compiled and analyzed using Floristic Quality Assessment software developed by the Conservation Research Institute [21]. C-values, originally devised for the flora of the Chicago region by Swink and Wilhelm [22], rank native species from 0–10, with higher numbers indicating greater preference for high quality habitat and less tolerance of disturbance (Table 2). Mean C-value acts as a species-weighted index of relative habitat integrity, based on the assumption that plants effectively integrate biotic and abiotic condition of ecological systems.

Table 2. Conceptual ranges of native species' tolerance to disturbance and fidelity to natural communities based on C-value (from [23]). Non-native species are assigned C-values of zero by default when total mean C-value, that is the mean of all species at a site, is calculated.

C-value range	Species characteristics
0–3	Species that provides little or no confidence that their inhabitation signifies remnant conditions
4–6	Species that are typically associated with remnant plant communities, but tolerate significant or moderate disturbance
7–8	Species found in high-quality remnant plant communities that appear to endure, from time to time, some disturbance
9–10	Species restricted to remnant landscapes that appear to have suffered very little post-settlement trauma

We chose C-values because we wanted a measure we could use with our inventory data that, in a single value, would allow comparison between sites and which would provide a base-line with which to look for change in the future. C-values provide an *a priori* standardized way to do this.

Coefficients of conservatism have proven reliable in conservation and restoration studies. They continue to be developed and employed. They have been developed for over 12 states and provinces, most recently South Florida (2009), Minnesota wetlands (2010), the flora of the Northeastern US (2010) and coastal Louisiana (2011). Although a few studies (*e.g.*, [24,25]) have found limitations in the effectiveness of C-values to reflect habitat quality based on other measures, C-values have been independently confirmed to reflect habitat quality and integrity and degree of anthropogenic habitat disturbance in other studies. Plant communities for which C-values have proved efficacious include tallgrass prairie (*e.g.*, [26,27]) and wetlands (*e.g.*, [28–31]). Spyreas and Matthews [32] found plants with high C-value occur in highly diverse forests in Illinois and that C-values are good surrogates for

biodiversity. In addition, mean C-values have been shown to be cost-effective tools for monitoring responses to treatments and disturbances in prairie restorations (e.g., [33]).

As C-values have come in to more common use, caveats have been recognized. One is that they are best used to compare sites within the same plant community type, not across types. Here, we use them to compare forested remnant sites in Indianapolis, a county that was 98% forested in pre-settlement times. Any biases built into the assignment of values will be consistent across sites. We do not use the Floristic Quality Index, often derived from C-values, because it can be sensitive to area sampled and our sites are of varying size. Another issue is sensitivity to sampling date based on plant phenology. We sampled all sites throughout the growing season to get a full picture of the flora at each site. C-values have also been criticized for being biased toward rare species or by personal preference. The consultation of a fairly large number of experts, eight, in assigning C-values to plants in Indiana decreases possible influence of the latter, while the lack of many rare plants in central Indiana decreases the likelihood of the former.

Plants listed as native are considered native to Indiana, having been established here before the time of European settlement. A subset of non-native species were further classified as invasive based on their listing as invasive non-native landscaping plants by the Midwestern Invasive Plant Network and the Invasive Plant Species Assessment Working Group [34] or “most unwanted” invasive plants by the Indiana Agricultural Pest Survey Program [35]. Indiana has no official single state list of species considered invasive.

Finally, we examined relationships between mean native C-value and other site parameters, including number of non-natives and number of invasive species present by conducting Spearman rank order correlations in the R v2.6.2 statistical software environment [36].

3. Results

The number of species per site ranged from 105 to 363 (Table 3). When inventory counts reach 100 species or more, mean C-values are thought to be stable, not likely to be appreciably influenced by the discovery of additional species [23], so our values are derived from a robust sample size. Species per ha ranged from 0.72 to 19.6. Native species dominated, with non-natives averaging 19.3% across all sites. Three sites (ECNP, SPNP, and WGP) were comprised of over 90% natives.

Thirty-four species with C-value ranks in the range 8–10, indicative of high quality habitat, were found (Table 4). Smooth blue aster (*Symphyotrichum laeve*) was the only C-value 10 species, found at a single site, ECNC. Two C-value 9 plants, glade fern (*Diplazium pycnocarpon*) and small woodland aster (*Helianthus microcephalus*), were found at only two (FHSP, WGP) and one (ECNC) site, respectively. Over all, the sites averaged 6.1 high quality species. ECNP, WGP and FBSP had the most high quality species with 10, 10, and 11, respectively. The most frequently encountered high quality species was American beech, with a C-value of 8, found at 11 of the 14 sites.

Mean C-values per site for native species ranged from 3.0 to 4.5 (Table 3), with some of the smallest preserves having the largest values. Total mean C-values when all species are considered (non-natives in this case have a C-value of zero), are lower, ranging from 2.1 to 4.0. For all but 5 of the 14 sites (ECNP, ECNC, MPNP, SPNP and WGP), the difference in mean C with and without

non-natives differed by 0.7 units or more, the value at which natural quality is likely to have been compromised by the presence of non-natives [23].

Table 3. Floristic quality analysis of inventory results by site for the Marion County, Indiana, USA.

Site	# Species	% Non-native	Mean Native C-value	Total Mean C-value
ANP	213	30.0	3.0	2.1
CSS	314	26.1	3.4	2.5
ECNC	154	13.6	4.5	3.9
ECNP	154	6.5	4.5	3.9
FHSP	363	20.7	3.7	3.0
JSP	176	25.0	3.5	2.6
MCC	172	16.9	3.7	3.0
MPMT	172	25.0	3.5	2.6
MPNP	105	11.4	3.8	3.3
MUEL	334	30.4	3.3	2.6
SPNP	161	7.5	3.8	3.6
SWWP	253	20.9	3.6	2.8
TRSP	172	27.9	3.2	2.3
WGP	138	8.0	4.4	4.0
Average			3.7	2.9
Std. Error			0.13	0.16

Non-native invasive species, also numbering 34, were recorded in our inventories (Table 5 and Table 6), accounting for 3–10% of species present at each site. Most of these were woody (Table 4) with an average of 8.6 per site. ECNP had the fewest of these woody species with only four and CSS had the most with 13 (Table 4). Eleven species were not widespread, being present in only one or two sites. Of the most prevalent non-native invasive woody species, five are honeysuckles in the genus *Lonicera*. Specifically, Amur honeysuckle (*Lonicera maackii*) was found at all 14 sites. Japanese honeysuckle (*Lonicera japonica*) was present at 12. The woody vine winter creeper (*Euonymus fortunei*) was the next most common species, found at 10 sites.

Twelve species of herbaceous plants considered invasive were found, with an average of 5.4 species per site (Table 6). CSS and SWWP had the most, with ten species each, MPNP, SPNP, and WGP each had one. The most commonly encountered species was garlic mustard (*Alliaria petiolata*), found at 13 of 14 sites.

Data across all sites indicate a strong relationship between non-native species presence and mean native C-value, two independent measures of habitat integrity. Total number of non-natives was significantly negatively correlated with mean native C-value ($r_s = -0.78$, $p < 0.001$). A similarly strong relationship was found between the number of invasive species present at a site and mean native C-value ($r_s = -0.78$, $p < 0.001$), even though invasive species account for only 3–10% of the species present. These results are independent of area. Total number of non-natives and total number of invasive species were not significantly correlated with size of sites.

Table 4. High C-value (8–10) species found during inventories of 14 natural areas in Marion County, Indiana, USA.

[illegible]

Table 4. Cont.

USDA Name	Common Name	C Value	ANP	CSS	ECNC	ECNP	FHSP	JSP	MUEL	MPNP	MPMT	SPNP	SWWP	MCC	TRSP	WGP
<i>Rudbeckia fulgida</i>	Orange coneflower	8						x								
<i>Sanicula trifoliata</i>	Largefruit blacksnakeroot	8			x								x			
<i>Solidago patula</i>	Roundleaf goldenrod	8		x					x				x			
<i>Symplocarpus foetidus</i>	Skunk cabbage	8							x							x
<i>Trillium grandiflorum</i>	White trillium	8			x					x						x
<i>Trillium nivale</i>	Snow trillium	8					x									
<i>Veronicastrum virginicum</i>	Culver's root	8							x							

Table 5. Non-native invasive woody plant species found during inventories of 14 natural areas in Marion County, Indiana, USA.

Latin Name	Common Name	Life Form	ANP	CSS	ECNC	ECNP	FHSP	JSP	MUEL	MPNP	MPMT	MCC	SWWP	SPNP	TRSP	WGP
<i>Acer platanoides</i>	Norway maple	T					x		x							
<i>Ailanthus altissima</i>	Tree of heaven	T	x	x				x			x	x			x	x
<i>Alnus glutinosa</i>	European alder	T					x									
<i>Berberis thunbergii</i>	Japanese barberry	S					x					x		x		x
<i>Catalpa bignonioides</i>	Southern catalpa	T					x									
<i>Celastrus scandens</i>	American bittersweet	V					x	x								
<i>Elaeagnus umbellata</i>	Autumn olive	S		x	x						x			x		
<i>Euonymus alatus</i>	Burningbush	S	x		x	x							x	x		
<i>Euonymus fortunei</i>	Winter creeper	V	x	x				x	x	x	x	x	x		x	x
<i>Frangula alnus</i>	Glossy buckthorn	T							x							
<i>Hedera helix</i>	English ivy	V								x						
<i>Ligustrum obtusifolium</i>	Border privet	S	x		x											x
<i>Ligustrum vulgare</i>	European privet	S		x			x									
<i>Lonicera japonica</i>	Japanese honeysuckle	V	x	x	x	x	x	x	x		x		x	x	x	x
<i>Lonicera maackii</i>	Amur honeysuckle	S	x	x	x	x	x	x	x	x	x	x	x	x	x	x
<i>Lonicera morrowii</i>	Morrow's honeysuckle	S	x	x			x				x				x	
<i>Lonicera tatarica</i>	Tatarian honeysuckle	S				x									x	
<i>Lonicera X bella</i>	Showy fly honeysuckle	S							x							

Table 5. Cont.

Latin Name	Common Name	Life Form	ANP	CSS	ECNC	ECNP	FHSP	JSP	MUEL	MPNP	MPMT	MCC	SWWP	SPNP	TRSP	WGP
<i>Morus alba</i>	White mulberry	T	x	x				x	x	x	x		x		x	
<i>Polygonum cuspidatum</i>	Japanese knotweed	S		x							x					
<i>Rhamnus cathartica</i>	Common buckthorn	S							x							
<i>Robinia pseudoacacia</i>	Black locust	T	x	x			x	x	x	x	x				x	
<i>Rosa multiflora</i>	Multiflora rose	S		x	x		x	x	x			x		x		
<i>Ulmus pumila</i>	Siberian elm	T		x							x				x	
<i>Vinca minor</i>	Common periwinkle	V	x	x	x				x	x	x		x			

Life forms: T = tree, S = shrub, V = vine.

Table 6. Non-native invasive herbaceous plant species found during inventories of 14 natural areas in Marion County, Indiana, USA.

Latin Name	Common Name	ANP	CSS	ECNC	ECNP	FHSP	JSP	MUEL	MPNP	MPMT	MCC	SWWP	SPNP	TRSP	WGP
<i>Alliaria petiolata</i>	Garlic mustard	x	x	x	x	x	x	x	x	x	x	x		x	x
<i>Cirsium arvense</i>	Canada thistle	x	x		x	x	x			x		x		x	
<i>Coronilla varia</i>	Crownvetch	x	x			x				x				x	
<i>Dipsacus laciniatus</i>	Cutleaf teasel		x				x			x		x			
<i>Euphorbia esula</i>	Leafy spurge	x										x		x	
<i>Glechoma hederacea</i>	Ground ivy	x	x	x		x	x	x		x	x	x	x	x	
<i>Hesperis matronalis</i>	Dames rocket		x		x		x					x			
<i>Humulus japonicus</i>	Japanese hop	x	x									x			
<i>Lysimachia nummularia</i>	Creeping jenny	x	x			x		x			x	x		x	
<i>Melilotus officinalis</i>	Sweetclover	x	x			x		x		x		x		x	
<i>Ornithogalum umbellatum</i>	Sleepydicke					x	x	x							
<i>Phalaris arundinacea</i>	Reed canarygrass		x		x		x	x		x		x		x	

4. Discussion

4.1. Presence of High C-Value Species

Remnants of high quality habitat remain in Marion County, as reflected by the presence of plants with high coefficient of conservatism values. Although we found few species with C-values of 9 or 10, the 32 species with ranking of 8 indicate the presence of remnant plant communities of fairly high integrity that are able to endure some disturbance [20]. The most commonly encountered high C-value species across the study sites included American beech, a signature tree of the beech-maple forest that characterized presettlement central Indiana. The single C-value 10 species, smooth blue aster, is found in sandy soil in oak woods and clay soils of stream bluffs in central Indiana [37]. Likewise, the two C-value nine species (glade fern and small woodland aster) are associated with dry wooded slopes and slopes of ravines in beech woods in deep humus [37,38]. Ravine and bluff habitats in central Indiana were mostly spared from conversion to agriculture or building and development as the county was urbanized, making the persistence of high C-value species of these habitats more likely than plants of other habitats. This is the case for each of the three sites in our study where these species were found. In contrast, previous studies have documented the disproportionate extirpation of high-quality species from wetlands over the last 70 years in Marion County due to land conversion [39].

Populations of extant high C-value plants in Marion County are likely relicts that have been in place a long time. Historical records of specimens in the Friesner Herbarium indicate that high C-value plants seen in recent surveys at WGP are self-sustaining populations that have been present for over 70 years. Glade fern was collected at the site in 1933. Some plants of conservation concern monitored by the Natural Heritage database in California have also been found to persist in human-dominated landscapes, contributing to overall biodiversity conservation of these sites [10].

4.2. Mean C-Values

While overall site quality can be inferred from the presence of individual high quality species, mean coefficient of conservatism values offer a more integrated view of the flora present at a site. Mean C-values for native species in our 14 sites were in the range of 3–4. Despite these seemingly low values, our inventories indicate several of our sites at the time they were surveyed had values comparable to the best quality reference sites in central Indiana (*i.e.*, 3.8–4.1), based on a review by Rothrock and Homoya [23]. Five of our sites had greater values, with three (WGP, ECNP and ECNC) having values of 4.4, 4.5 and 4.5, respectively. C-values for the best natural sites in the Central Till Plain of central Indiana plateau are in the low 4 range, lower than other regions of the state, due to a region-wide limited number of high-quality species, although whether this is due to historical or biological reasons is not known [23].

4.3. Non-Native and Invasive Species

The number of non-native species in the Indiana flora has been increasing over time. Fourteen percent of species growing outside of cultivation in 1940 were non-native [38]. Recent estimates put the percentage at 31 [40] statewide. Our inventories found a smaller overall percentage of non-natives,

19.3%, indicating the Indianapolis urban areas sampled had not been as impacted by introduced species as other habitats in the state. For example, the three nature preserve sites had very low numbers of non-natives. These data support the findings of Ehrenfeld [41] that, contrary to widely held notions, not all natural areas in urbanized areas are highly invaded.

Relatively few of the non-native species in the Indiana flora are considered invasive, causing ecological damage as they spread prolifically in natural areas. In our surveys, most invasives were woody plants. The most commonly encountered, Asian honeysuckle species in the genus *Lonicera*, are the subject of costly eradication efforts. They, and several other of the woody invasive species identified in our studies, were intentionally planted by the Indianapolis Parks Department in the early part of the twentieth century along boulevards throughout the city [39]. Asian bush honeysuckles are found primarily along the margins of woods in the Midwestern United States, but can spread into deeper cover. These species are now known to reduce presence of native herbaceous species such as spring ephemerals due to their phenology, leafing out earlier and keeping their leaves longer than native shrubs [42]. Their berries are also harmful to wildlife, being preferred by neotropical songbirds who are responsible for their spread. In addition, Asian bush honeysuckle berries are higher in sugars than fats and so do not contribute to calories needed for migration as well as native fruits do [43]. Lastly, their branching architecture encourages nest predation [44].

Garlic mustard, the most commonly encountered invasive herbaceous species is a more recent arrival in central Indiana. This biennial was first documented in the state in 1968 [40]. Based on records in the Friesner Herbarium of Butler University, it was not present in Marion County until the 1970s. Plants are self-compatible, producing thousands of gravity-dispersed seeds that survive for years in the seed bank [45]. Garlic mustard degrades habitat by creating monoculture stands that compete with native flora. There is also evidence that it inhibits the regeneration of forest trees [46]. It is shade-tolerant and capable of becoming permanently established in high-quality forests, with presence increasing rapidly with periodic disturbance [47].

Five study sites consistently ranked the highest in habitat quality (ECNP, ECNC, MPNP, SPNP and WGP), based on mean native C-value, the difference in mean C-value with and without non-natives, percent non-natives, and number of invasive species. This result supports a 1994 report by Brothers [48] that identified four of the five sites as the best remaining examples of what pre-settlement forests might have looked like in Indianapolis. Three of these sites (ECNP, SPNP, and MPNP) are designated state-dedicated nature preserves. This designation indicates high natural area quality, which lead historically to their selection. It also influences current management; state-designated properties are afforded additional exotic species control. The fourth site identified by Brothers [48], WGP, is a city park with limited public access and no well-developed trails. This isolation likely accounts for the low number of invasive species present, with reduced opportunity for seed dispersal into the park. ECNC is near the former nature center of a large city park. The area was often scouted by park naturalists who led field trips in the woods and removed exotics as they encountered them. There may also have been some “enrichment” to the woods, planting in of high-quality natives by park staff for educational purposes.

Among sites with the lowest habitat quality based on C-values and numbers of invasive species, ANP CSS, MPMT and TRSP had the greatest difference between mean C-value of native plants and mean total C-value, indicating that their natural quality is being impacted by the presence of non-natives as a whole, not just invasive species. Two of these sites received the greatest historical

habitat alternation and are still recovering from disturbance. The Art and Nature Park site (ANP) is the most disturbed of the study sites, a former farm field in the 1920s and gravel pit in the 1950s, with only narrow strips of wooded area present currently. It has recently been developed into a nature park and is receiving intense removal of invasive species to promote reestablishment of native plants. Cold Spring School (CSS), an Indianapolis Public Schools Environmental Science Magnet School is on the site of a former estate. It has been the focus of student, teacher, and community volunteer ecological restoration efforts. Much of the site is a former fen, with small remnants of woods. The two other sites (MPMT and TRSP) are city parks with heavy trail use by walkers and cyclists. The trails may be avenues for the spread of invasive species' seed.

4.4. Conclusions

Our results document that Indianapolis/Marion County contains several remnant habitat preserves that are of comparable quality to the best quality remnant known for central Indiana. Recent estimates rate 13% of Marion County having medium to dense forest cover [18]. This cover is present primarily along the county's major river, White River, and its tributaries and in older residential areas. As can be seen in Figure 1, many of our parks are along the river. The river may facilitate connectivity between our sites and serve as a conduit for seeds and wildlife.

High-quality habitat remnants remain in Indianapolis despite historical and current disturbance. The highest quality sites in our study are three state-dedicated nature preserves, a site that receives special stewardship from park naturalists, and a site that has limited public access, with no trails to serve as corridors for seeds of invasive plants. These results indicate that the state has indeed protected worthy sites and that, with continued stewardship to address invasive species, habitat quality has been preserved. Continued environmental stewardship will be needed at all sites in the future in order to provide residents with contact with nature that reflects the characteristics of pre-urbanized Indianapolis.

The distribution, and many other attributes, of preserved patches of natural vegetation in inner urban areas were determined decades ago, as noted by Stenhouse [49], and cannot be changed now. However, our results document that high quality natural areas, reflecting biodiversity comparable to the best regional reference sites, can persist in urban settings. For Indianapolis, land protection efforts made decades ago continue to benefit citizens today.

We are not aware of studies that use C-values to evaluate urban flora in other parts of the state or in other states, so it is not yet possible to interpret how generalizable our results are. Comparisons with values from other states would need to be relative, since coefficients of conservatism are developed independently for different geographic areas, reflecting differences in habitat specificity of species across their ranges. We feel the methods employed here should be applied to other urban areas, both currently built and planned, to help identify and protect quality habitat remnants. With developed area in the United States predicted to nearly double over the next 20 years [16], these habitats will only be at greater risk in the future.

Our finding of a strong inverse relationship between the number of invasive species present at a site and mean native C-value provides independent corroboration that in our urban Midwestern, USA setting, C-values are valid indicators of habitat quality. Non-natives, especially invasive species, are generally associated with reduced habitat quality. While this relationship is not surprising, our

inventories provide numbers to quantify the relationship and the strength of the correlation is surprisingly strong.

The message from our work for land managers and planners is that high-quality natural habitat can persist in older American Midwestern cities and that these sites should be looked for, documented and stewarded. In areas of new urbanization, even relatively small patches of native vegetation are worth preserving as, if they receive the correct management, habitat quality equal to the best regional sites can be maintained.

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