

Management effects on plant community and functional assemblages in Chicago's vacant lots

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Abstract

Question: We ask whether 11-year mowing patterns and presence of fencing influence plant community diversity and functional assemblage in urban vacant lots.

Location: This study took place in 34 vacant lots on the south and west sides of Chicago, IL, USA. Urban vacant lots are an excellent study system in which to investigate the effects of management in cities: they are ubiquitous in many cities and they experience a range of management, particularly mowing and fencing.

Methods: We used municipal data to classify infrequent and intensive mowing regimes and assessed presence or absence of fencing in situ. In our sites, these management strategies are independent. We used individual permutational analysis of variance (PERMANOVA) models to assess the effects of these management strategies on plant community composition. We then assessed species richness of plants with various traits using six individual two-way ANOVA models with interaction terms. Our predictor variables included management strategies (mowing intensity and fencing) and three plant traits (growth form [graminoid, forb, or woody], life duration (annual, biennial, or perennial), and biogeographic origin [native or introduced]).

Results: We found 120 plant species in the vacant lots. Most of these species were perennial, introduced forbs. We found no discernable effects of mowing intensity on plant community composition or richness of plants in the three functional groups. However, when we compared the species found along fences to those in lot interiors, we found significantly different plant communities. Fence line communities had significantly more native and woody species than lot interiors.

Conclusions: Plant communities differ at very fine spatial scales within an individual vacant lot, and this pattern is related to the presence of fences. Overall, vacant lots support diverse plant communities which can differentially contribute to wildlife habitat depending on management strategy.

KEYWORDS

Chicago, fencing, management, mowing, plant traits, spontaneous urban plants, succession, vacant lots, wastelands

1 | INTRODUCTION

Across the globe, land management by humans is a critical driver of ecosystem form and function. As defined by Erb et al. (2017), land management refers to land use activities that result in “land modifications” without changing the land cover type. When all types of land management are added up, the effect is staggering; Erb et al. (2017) report that 80% of the 130 Mkm² of ice-free land experiences some level of land management. Of this, almost half can be classified as “grazing and mowing”, and the majority of the rest consists of forest and cropland harvesting. These management activities modify the landscape for human use or support, and extend through urban, rural, and “natural” landscapes. Despite the prevalence of these activities, there are still large knowledge gaps related to the effects of land management (Keesstra et al., 2018). It is clear, however, that the initiation or modification of land management has dramatic effects on biodiversity and ecosystem function (Foley et al., 2005).

One of the most common and widespread plant management tools is mowing (Erb et al., 2017). Managers have different motivations for mowing, but it ultimately results in chopping tall plant stalks to a consistent height. This displacement of plant tissue is decidedly different than that from grazing or burning (Kahmen & Poschlod, 2008) and differentially affects the survival, growth, and reproduction of certain species (Moog, Poschlod, Kahmen, & Schreiber, 2002). These species-specific adaptations and responses result in plant community compositional and functional changes in response to mowing over time. However, community responses to mowing are different across biogeographic regions. In rural European grasslands where mowing has been studied extensively, Milberg, Tälle, Fogelfors, and Westerberg (2017) show increased species richness with increased mowing, and Stammel, Kiehl, and Pfadenhauer (2003) and Valkó, Török, Matus, and Tóthmérés (2012) suggest that regular mowing favors forb establishment. Conversely, Collins, Knapp, Briggs, Blair, and Steinauer (1998) found that mowing was most critical for retaining C₃ grasses in fire-dependent North American grasslands. In some systems, mowing increased non-native annual species (Davies, Bates, & Nafus, 2012), while it increased native perennials in others (Verrier & Kirkpatrick, 2005). Modeling evidence suggests that the rate of mowing matters: less frequent mowing facilitates perennial establishment and growth (Schippers & Joenje, 2002), but there is a transition from a perennial-dominated community to an annual-dominated community with increasing mowing disturbance (Schippers, Groenendaal, Vleeshouwers, & Hunt, 2001). In addition to intensity, timing of mowing also drives changes in plant community composition. Delaying spring mowing may increase species richness (Humbert, Pellet, Buri, & Arlettaz, 2012) and reduce forb dominance (Hazell, 1965), although Chaudron, Chauvel, and Isselin-Nondedeu (2016) do not support these findings. The effects of mowing are likely complicated by the fact that mowing itself can introduce an unintended source of seeds, as tractor mowers are notorious vectors of seed dispersal between sites (Strykstra, Bekker, & Verweij, 1996; Strykstra, Verweij, & Bakker, 1997); Chaudron & Isselin-Nondedeu, 2017. Furthermore, recent evidence demonstrates that mowing

interacts strongly with hydrology to influence plant community composition (Kołos & Banaszuk, 2018), suggesting the importance of location and biophysical conditions to mowing outcome.

Widespread as mowing is across the globe, most ecological data on the effects of mowing come from rangelands, crop fields, and grassland restoration sites. However, mowing is one of the most common types of land management in urban areas, but there is no consensus on the biodiversity effects of this practice in cities. Studies in Europe (France: Politi Bertoncini, Machon, Pavoine, & Muratet, 2012; Chollet, Brabant, Tessier, & Jung, 2018; England: Helden & Leather, 2004) report higher species richness when urban mowing is reduced, but a global review (which also included gray literature) reported higher plant richness and forb diversity in urban rights-of-way and roadsides when they are mowed more frequently (Jakobsson, Bernes, Bullock, Verheyen, & Lindborg, 2018). Finally, several studies indicate a complex but poorly understood interplay between mowing and removal of plant clippings versus mulching of clippings in place (Moog et al., 2002; Kahmen & Poschlod, 2008; Jakobsson et al., 2018). As conservation strategies shift to include cities' unique habitats, there is a need to understand how urban plant community structure is shaped by mowing management across biogeographic regions (Aronson et al., 2017).

Fencing is a common management tool that is used to control movement of people or wildlife across a landscape. In restoration and management, fencing is most often used to exclude large herbivores from the plant community (Bakker, Ritchie, Olf, Milchunas, & Knops, 2006; Borer et al., 2015; Tarhouni, Ben Hmida, Ouled Belgacem, Louhaichi, & Neffati, 2017). However, fencing also adds structural complexity to a landscape, which in turn could affect how seeds are dispersed into or out of the plant community. Fencing may serve as perching sites for birds, and studies have shown higher seed rain and seedling establishment of bird-dispersed species under perching sites (McDonnell, 1986; Holl, 1998; Gosper, Stansbury, & Vivian-Smith, 2005). Fencing may also act as a physical barrier for wind-dispersed seeds and as a structure for climbing vines (Fike & Niering, 1999). In addition to these direct fencing effects, it is also more difficult to operate mowing machinery along fence lines, so there may be synergistic effects of mowing and fencing on the plant community.

Urban vacant lots are an excellent system in which to study the ecological effects of mowing and fencing on the plant community. Because they are ubiquitous in many cities (Newman, Bowman, Jung Lee, & Kim, 2016) and receive varying levels of management, vacant lots provide the necessary fine-scale variation to conduct an urban “natural experiment” (Felson & Pickett, 2005). In Chicago, IL (USA), where this study takes place, mowing of vacant lots typically occurs when neighbors call in to complain about overgrown vegetation. Furthermore, fencing is frequently installed along one or more sides of a vacant lot and remains in place long-term. Beyond mowing and fencing, the direct human impacts on these spaces are fairly low (Anderson & Minor, 2019), and they are generally easy to access for vegetation samples. There has been interest recently in revitalizing vacant lots to serve a more robust ecological role in cities (Anderson

& Minor, 2017), and understanding how the plant community forms and functions in these spaces are foundational to this goal.

In this paper, we describe the effects of mowing and fencing on plant communities in 34 vacant lots in Chicago. Specifically, we address the following questions:

1. How do mowing and fencing shape plant community composition in vacant lots?
2. Are particular plant species strongly associated with either management strategy?
3. Do different management strategies create functional differences in the plant communities?

Based on the contradictory patterns in the literature, we were unsure of how our urban plant communities would respond to mowing. However, given the frequency of mowing in some lots, we suspected that increased mowing might select for annual species that can survive and set seed even with regular biomass loss. Furthermore, we expected that fences might facilitate establishment and growth of different species than lot interiors, and these would likely be dominated by taller woody vegetation. Ultimately, we aimed to address whether the heterogeneous plant communities and habitat types found in vacant lots are a result of fine-scale variations in management practices.

2 | MATERIALS AND METHODS

2.1 | Study area

Our study took place in Chicago, Illinois, USA. Chicago is the third-largest city in the United States by population (Rigolon & Németh, 2018). It is located along the western coast of Lake Michigan, and has a temperate climate, with four pronounced seasons. Average summer temperatures range from 16°C (low) to 28°C (high) and average winter temperatures range from -8°C (low) to 0°C (high) (US National Weather Service: www.weather.gov). Soils across the city are characterized by the SSURGO soils database (Soil Survey Staff, USDA Web Soil Survey, <https://websoilsurvey.sc.egov.usda.gov/>) as "urban", and previous research at these sites suggests that available soil data do not explain variation in plant diversity in vacant lots (Anderson & Minor, 2019).

At the time of sampling, the city owned 13,703 vacant lots, most of which were clustered in low-income neighborhoods in the west and south sides of the city. We selected 34 vacant lots across Chicago for this study. To do this, we first randomly selected 150 sites from the City-Owned Land Inventory (https://www.cityofchicago.org/city/en/depts/dcd/supp_info/city-owned_land_inventory.html) and used Google Earth Pro© Street View to ensure vacancy and accessibility. We eliminated any sites that were completely fenced (due to access difficulties) or were no longer vacant. From this, we sampled the first 34 lots that met our criteria. These lots were the same as those used in our previous research (Anderson &

Minor, 2019), with one omission. Of these 34 lots, 20 had a chain-link or steel security fence on at least one side. It is difficult to ascertain the first date of vacancy in these lots, but an assessment of historic aerial photographs in Google Earth Pro showed that all except one of these sites have been vacant and unbuilt since at least 1999 (Anderson & Minor, 2019).

2.2 | Plant sampling and classification

In mid-summer 2015, we conducted area-based vegetation samples of vacant-lot interiors and their fenced edges. To sample the interior, we used a 2 m × 2 m grid that covered the entire lot except a 1-m buffer adjacent to fences and building edges. At each intersection of the gridlines, we identified all species of herbaceous plants and woody seedlings that touched a meter stick placed at the point. We also censused all trees greater than 10 cm DBH (diameter at breast height) in the lot. For lots with fences, we compiled an additional species list by walking along the fence lines and identifying all species growing within 0.5 m of the fence. For all analyses, we compressed the sampled species lists into presence/absence data for lot interiors and fence lines (if applicable), since we did not have a measure of plant abundance along the fence lines.

For each plant species observed in a lot, we collected some information on its morphology and biology from the USDA PLANT database (<https://plants.sc.egov.usda.gov/java/>). First, we identified growth form as graminoid (grasses and sedges), forb (broadleaf herbaceous plants), or woody (including woody vines, trees, and shrubs). Additionally, we classified species according to their biogeographic origin (native or introduced) and life cycle duration (annual, biennial, or perennial, referred to as "duration" from here on) based on county-level records. We were unable to identify 27 specimens to species. For these species, we classified growth form and included them in that analysis. However, we eliminated these unidentified species from any analysis of origin and duration.

2.3 | Characterization of the mowing regime

In Chicago, city-owned vacant lots are mowed by hired contractors. We filed a "Freedom of Information Act" (FOIA) request to obtain records from the city about mowing events in the vacant lots between January 2006 and October 2015. Digitized mowing records for our sites were not available prior to 2006. We used three measures to describe the mowing pattern in each vacant lot: total number of mowing events, total number of years in which mowing occurred, and number of years since the last mowing event. Together these three variables describe the intensity and evenness of mowing over the 11-year period.

To characterize the mowing regime at each lot, we used a *k*-means cluster analysis to identify groups of vacant lots with similar mowing patterns. This technique divides a multivariate dataset into a user-specified number (*k*) of natural groups or clusters. We used

the three mowing variables to cluster the vacant lots, and standardized the variables prior to analysis. To identify the optimal number of clusters, we used the elbow method (Kodinariya & Makwana, 2013). We first ran *k*-means clustering on the dataset for a range of values of *k* (2–5). For each value of *k*, we calculated the total within-cluster sum of squares, plotted this value against the number of clusters, and looked for the first inflection point, i.e. the “elbow.” We selected the value of *k* for which adding additional clusters did not dramatically reduce the sum of squares.

Once we identified the optimal number of clusters, we tested for differences in the three mowing variables between the clusters using a separate two-sample *t* test for each variable. When we were satisfied that the clusters represented sites with different mowing regimes, we used these clusters to test the effect of mowing on the plant community.

2.4 | Statistical analysis

To understand the effects of management on the plant community, we wanted to determine whether fencing and mowing were independent management decisions. We used Fisher's exact test to test for non-random associations between these categorical variables. We constructed a 2 × 2 contingency table based on mowing intensity (infrequent versus intensive, as defined by the cluster analysis) and presence/absence of a fence, and calculated the test statistic to determine if there were any associations between our two management tools.

The next step was to examine the effect of mowing and fencing on plant community composition and functional groups. Because not all of our lots had fences, we assessed the effect of mowing and fencing on plant communities separately. To examine the effect of fencing, we compared the plant community within 1 m of a fence to the plant community in the interior of the same lot.

2.5 | Plant community composition

To examine the impact of mowing intensity on the plant community of vacant-lot interiors, we conducted a permutational multivariate analysis of variance (PERMANOVA, Anderson, 2017) with 9,999 permutations on the full presence/absence community matrix using the “adonis” function (vegan package in R 3.5.1, R Core Team, R Foundation for Statistical Computing, Vienna, Austria). The explanatory variables in this model were mowing clusters (infrequent versus intensive, as determined by *k*-means clustering) and the number of points sampled at a given lot. The latter term was included to account for our area-dependent sampling protocol. To visualize our results, we plotted community composition at each site, reduced into two-dimensional space using non-metric multidimensional scaling (NMDS) based on Bray–Curtis similarity (metaMDS function in the vegan package, R 3.5.1).

We also used a PERMANOVA and NMDS to evaluate the differences between the plant communities growing along the fence lines

and those growing in lot interiors. In this model, we compared the interior and fence line plant communities of the lots that had a fence ($n = 20$) using 9,999 permutations. Our model included location (fence line versus interior), mowing intensity, and the site address (lot number) as explanatory terms. We included site address as a variable to account for site-specific differences and biases. This method is a viable option for including the interdependence of a paired sampling design when there are a high number of species and a relatively low number of sites (Neale & Moffett, 2016; Seymour et al., 2016). We also included an interaction term for site location × mowing intensity.

We also tested for indicator species that were strongly associated with a particular mowing intensity or proximity to a fence line. To do this, we used the “multipatt” function (R package indicsp) with the “IndVal.g” species-site group association option. Although this test is capable of examining multi-level groupings, we ran separate indicator species analyses for mowing regime and fence line versus interiors and used the “duleg = TRUE” option to investigate only our original, independent management classes. When there are only two classes (e.g., fence line versus interior), this method works iteratively by randomly assigning each species to a category and then comparing these random assignments to the actual data and testing the best-matching patterns for significance. We ran one analysis on the lot interior community to test for species that associate with a particular mowing regime, and a second analysis – on the subset of vacant lots with fences – to test for species that associate with interiors or fence lines.

2.6 | Plant richness and functional diversity

To assess the effects of management on plant species richness and trait composition at each site, we used two-way analysis of variance (ANOVA) with species richness (α diversity) as the response variable. The two independent variables for the ANOVA were plant trait (growth form, biogeographic origin, or life duration) and management (either mowing intensity or fence line/interior). We could reliably classify growth form for all species, but statistics for origin and life duration were based on the subset of species we could positively identify. We included the interaction term to account for differing responses of plant traits to mowing or fencing.

3 | RESULTS

3.1 | Summary statistics

Across all lot interiors and fence lines, we identified 120 plant species (Appendix S1). Of these, we were able to identify 93 to species level. The remaining 27 species were classified by growth form and given a unique identifier. We identified 12 woody species, but forbs were by far the most common growth form (78 species). No single site had more than 42 plant species (mean ± SD, 20.2 ± 6.7 species). Nineteen species were only found along fence lines and 52 species

were only found in vacant-lot interiors. Three species (*Taraxacum officinale*, *Trifolium repens*, and *Trifolium pratense*) were found at over 90% of the site interiors, and three additional species (*Ulmus pumila*, *Oxalis stricta*, and *Solanum dulcamara*) were found along at least 80% of fence lines.

3.2 | Mowing classification

Based on the point of inflection of within-cluster sum of squares with increasing k , which showed little improvement when adding more clusters (Appendix S2), we generated two clusters of vacant lots that differed significantly in all included variables. Lots in cluster 1 experienced infrequent mowing while lots in cluster 2 were mowed more intensively. Cluster 1 lots had significantly fewer mowing events (two-sample t test, $t = 8.65$, $P < .0001$), were mowed for fewer years (two-sample t test, $t = 10.49$, $P < .0001$), and had been unmowed for longer periods of time (two-sample t test, $t = 3.93$, $P = .0006$) compared to lots in cluster 2 (Figure 1). With the exception of one lot, lots in cluster 2 had all been mowed in the most recent growing season. All lots were mowed at least once during the 11 years, but only one lot was mowed in all 11 years. From here on, we refer to these clusters by the mowing regimes they represent: “infrequent mowing” and “intensive mowing”, respectively.

3.3 | Independence of management strategies

Fisher's exact test indicated that mowing and fencing were independent elements of vacant land management ($P = .08$). However, an almost equal number of unfenced lots had intensive ($n = 6$) and infrequent ($n = 8$) mowing, while fenced lots were three times as likely to have an infrequent mowing pattern (Table 1), suggesting that this trend may approach significance with increased replication.

3.4 | Effects of mowing on the plant community

The PERMANOVA did not indicate a significant difference in the plant communities between lots with infrequent versus intensive mowing (Table 2). Furthermore, the plant communities showed no significant difference as a function of sampling intensity (measured as the number of sampled points). Visual inspection of our sites via multidimensional scaling (MDS) demonstrated no segregation in community composition between mowing clusters (stress 0.23; Figure 2). Our indicator species analysis corroborated this finding. No species were significantly associated with either mowing cluster (Appendix S1).

The ANOVA indicated that there was no effect of mowing intensity on species richness (Table 3). There also were no interactions between mowing intensity and functional groups of plants. However, there was a significant effect of growth form, biogeographic origin, and duration on species richness in the lot interiors

(Table 3). Regardless of mowing intensity, forbs were significantly more species-rich in vacant-lot interiors than graminoids or woody plants (Tukey's HSD, $P < .001$; Figure 3). Significantly more species in the vacant-lot interiors had a perennial life span (Tukey's HSD, $P < .001$; Figure 3). Finally, more lot interior species were introduced than native (Tukey's HSD, $P < .001$; Figure 3).

3.5 | Effects of fencing on the plant community

We found strong evidence of unique communities in different parts of vacant lots. Fence line communities differed significantly from those in the interior of the lots (PERMANOVA $df = 1$, $F = 9.48$, $P < .001$, Table 4). Among lots with a fence, there was a significant effect of mowing intensity and site on community composition, but the interaction term for mowing regime * location (fence line versus interior) was not significant. Overall, the PERMANOVA explained almost 73% of the variation in the plant community, and the MDS visualization demonstrated clear separation between the communities along fence lines and those in lot interiors (stress 0.21; Figure 4).

The ANOVA indicated that there was no significant difference in overall species richness between lot interiors and their corresponding fence lines (Table 5). However, there were significant interactions between fence line proximity and two of the three functional groupings. With respect to growth form, woody species richness was higher along fence lines than interiors (Tukey's HSD, $P < .001$; Figure 5), while graminoid richness was slightly higher in interiors (Tukey's HSD, $P = .07$; Figure 5). With respect to biogeographic origin, native species had higher richness along fences compared to lot interiors (Tukey's HSD, $P = .002$; Figure 5). Finally, while there were more perennials in our lots overall, there was no interaction between duration and fence lines proximity (Table 5).

The indicator species analysis (Appendix S1) revealed a strong association of several woody species with fence lines: *Fraxinus pennsylvanica* ($P = .021$), *Acer negundo* ($P < .001$), *Ailanthus altissima* ($P < .001$), and *Morus alba* ($P = .007$). The other two strong fence line associates were native species; *Parthenocissus quinquefolia* ($P = .0084$) is a climbing vine, and *Solidago altissima* ($P = .003$) is an early-successional tall-growing perennial.

Other species were significantly associated with lot interiors. All of the significant interior associates were non-native herbaceous plants. *Medicago lupulina* ($P = .001$) and *Trifolium repens* ($P = .002$) were found in the interior of almost every lot. *Capsella bursa-pastoris* ($P = .05$), *Polygonum aviculare* ($P = .001$), and *Tragopogon pratensis* ($P = .02$) were less common, but still fairly abundant across vacant-lot interiors.

4 | DISCUSSION

Chicago's vacant lots are areas of fairly high plant diversity. In 34 lots across the city, we identified 120 species, the majority of which were perennial, introduced forbs. To our knowledge, this work is among the

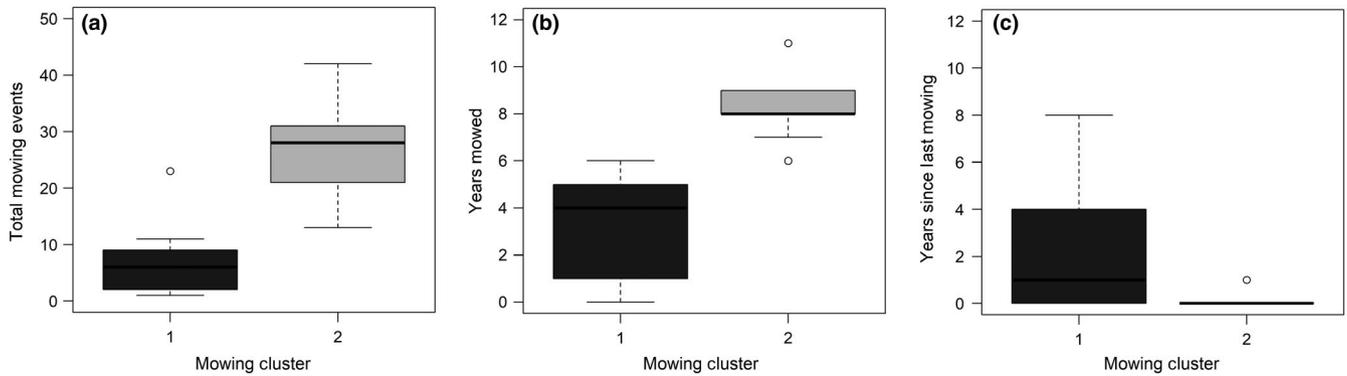


FIGURE 1 Results from *k*-means clustering of sites based on three mowing variables (total mowing events, years mowed, and years since last mowing) from records over 11 years. Cluster 1 includes vacant lots with infrequent mowing, and Cluster 2 includes lots with a more intensive mowing regime. Total number of mowing events, the number of years (out of 11) where a lot was mowed, and the years since last mowing were standardized prior to clustering, although raw data are presented here. Two-sample *t* tests indicate that clusters differ significantly in terms of the three measured variables ($P < .001$ for all tests)

TABLE 1 Associations of mowing and fencing as techniques to manage and control vacant land

	Infrequent mowing (cluster 1)	Intensive mowing (cluster 2)	Total
Fenced	15	5	20
Unfenced	6	8	14
Total	21	13	34

Fisher's exact test indicated that mowing and fencing are independent management strategies ($P = .08$).

TABLE 2 PERMANOVA results for community composition comparison between mowing regimes (infrequent versus intensive mowing)

Variable	<i>df</i>	<i>F</i>	R^2	<i>P</i>
Mowing category	1	0.73	.02	.75
Number of sample points	1	0.12	.02	.57
Residual	31		.95	
Total	33		1.00	

first to investigate the combined biodiversity effects of mowing and fencing management strategies in a North American city. Surprisingly, our results showed no effect of mowing regime over the past 11 years on plant richness, species composition, or functional composition in our lots. Fencing, however, was associated with distinct plant communities serving different functions within the same vacant lot. These results suggest that a land management decision intended primarily to restrict movement and access of people inadvertently contributes to a fine-scale patchwork of plant communities across an urban landscape. This heterogeneity provides habitat for a wider diversity of species and also provides a wider variety of ecosystem services.

Six plant species were strongly associated with fence lines. One fence line associate, *Parthenocissus quinquefolia*, is a climbing vine

that requires suitable substrate for growth. Of the remaining fence line associates, four were trees. *Morus alba* is dispersed by birds, which suggests that fences act as perches for birds. While we did not test this in this study, the association of *Morus alba* with fence lines suggests that bird dispersal and associated seed rain along fence lines may play a role in shaping biodiversity patterns in vacant lots. The other fence line-associate trees are *Acer negundo*, *Fraxinus pennsylvanica*, and *Ailanthus altissima*. These species are all wind-dispersed via large, samara-type seeds, which are likely to get caught in chain-link fencing and eventually germinate along the fence line. In the absence of mowing or other mechanical

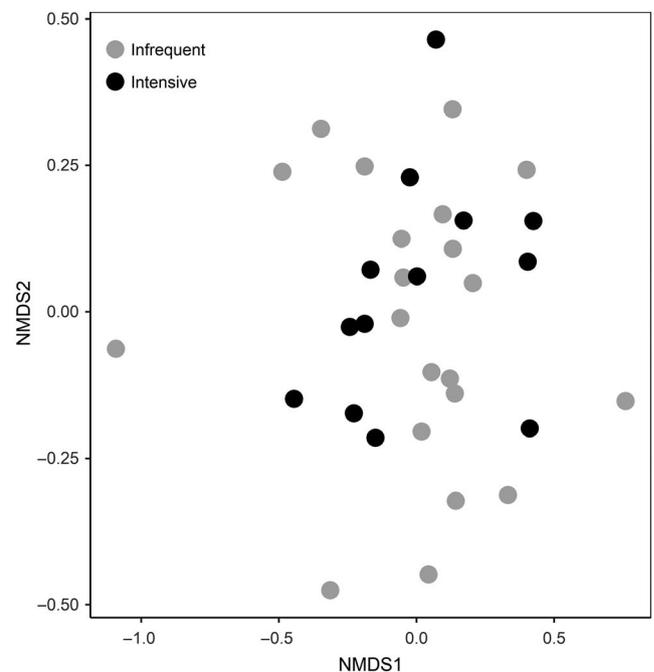


FIGURE 2 NMDS plot of differences in plant communities found in vacant lots experiencing infrequent mowing (dark gray; mowing cluster 1) and intensive mowing (light gray; mowing cluster 2). Distances are based on Bray-Curtis similarity. Total NMDS stress was 0.23

TABLE 3 Results of two-way ANOVAs for mowing and plant traits

	Model term	df	F	P
Growth Form	Mowing	1	0.27	.61
	Growth form	2	299.58	<.001
	Mowing * growth form	2	0.12	.89
Duration	Mowing	1	0.04	.85
	Duration	2	192.35	<.001
	Mowing * duration	2	0.47	.62
Origin	Mowing	1	0.03	.86
	Origin	1	213.87	<.001
	Mowing * origin	1	0.07	.8

“Growth form” includes forbs, graminoids, and woody species, “Duration” includes annual, biennial, and perennial species, and “Origin” includes native and introduced species. All models use species richness in lot interiors (≥ 1 m from fencing) as a response variable.

^aSignificant *P* values (at $\alpha = .05$) are denoted in bold.

removal, these four early-successional tree species grow rapidly (USDA Plants database: plants.usda.gov). This combination of seed capture and reduced disturbance due to the difficulty in mowing along fences suggests that vacant-lot fences are unique structures that support development of the urban canopy and provide habitat and perching sites for birds. Additionally, woody species along fence lines contribute to the provisioning of important ecosystem services such as cooling, pollution mitigation, and storm water uptake (Bolund and Hunhammar 1999), and deliver significant economic value (Kwok 2018). Furthermore, *Acer negundo* and *Fraxinus pennsylvanica* are both native to Illinois, and native trees are often preferable to exotic species for habitat provisioning and quality of biodiversity (Tallamy, 2009).

In contrast to the fence line species, all species strongly associated with vacant-lot interiors were forbs. *Medicago lupulina*, *Trifolium repens*, and *Polygonum aviculare* are among the strongest

indicators of vacant-lot-interior habitat. These diminutive species are common throughout the area (USDA Plants database), but prefer the open, sunny habitat readily found in lot interiors. *Trifolium repens* and *Medicago lupulina* provide critical resources to urban pollinators (MacIvor, Cabral & Packer, 2014), increasing the habitat value of vacant lots for a different set of species. The breakdown of species associated with vacant-lot fence lines and interior habitats supports the notion that vacant-lot plant communities can contribute to the habitat needs of two distinct taxa of conservation concern in cities – birds and bees.

The increase in woody species richness along fence lines in vacant lots could be leveraged in city greening plans and conservation goals. Not only do woody plants establish along fences, they also thrive there, where they are protected from trampling or accidental mowing. Greening projects that promote shrub growth along existing fence lines could potentially be quite successful. Reestablishment of trees and shrubs is a major challenge of sustainable urban forest development, and using existing fences to protect and promote cultivated or spontaneous woody growth could help advance this goal (Doroski et al., 2018). Cultivating shrubs along fence lines could support a “just green enough” model of urban greening by not drawing too much attention to restoration or greening efforts in low-income areas (Wolch, Byrne, & Newell, 2014). Alternatively, allowing spontaneous woody growth to develop along fence lines is tightly aligned with the ideas of “wild urban woodlands” put forth by Kowarik (2005). In this paradigm-shifting concept, spontaneous plants are viewed not as weeds or invasive species, but instead as free-to-establish, perfectly adapted species and novel communities that provide ecosystem services and habitat in cities. Certainly, some of the species found in our vacant lots are listed by the State of Illinois (plants.usda.gov) or the City of Chicago (Chicago.gov) as noxious weeds (see Table S1), where restrictions on sales and protocols for management are in place. However, less than 10% of the species we identified were listed, and of these, nine are already known to be localized on the landscape. While the idea of allowing exotic species such as *A. altissima* to grow unchecked in certain urban contexts contrasts with

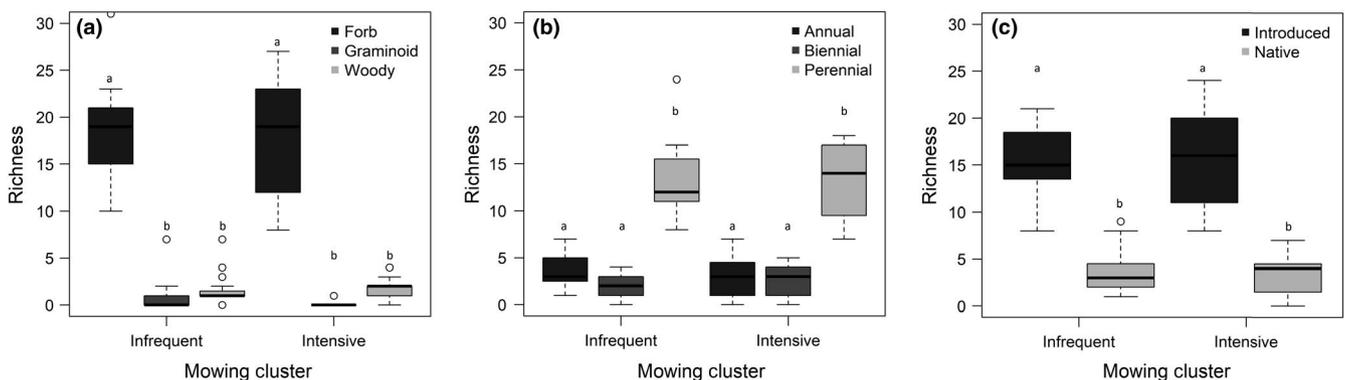


FIGURE 3 Functional composition of vegetation in lot interiors based on mowing regime (infrequent versus intensive) for (a) growth form (forbs, graminoids versus woody species), (b) life cycle duration (annual, biennial versus perennial species), (c) biogeographic origin (native versus introduced species). Different letters represent significantly different groups based on Tukey’s HSD pairwise comparisons at $\alpha = 0.05$

TABLE 4 PERMANOVA results for community composition comparison between fence lines and corresponding lot interiors

Variable	df	F	R ²	P
Fence location	1	9.48	.15	<.001
Site	18	1.88	.52	<.001
Mowing intensity	1	2.55	.04	.01
Location * mowing intensity	1	1.10	.02	.35
Residuals	18		.27	
Total	39		1.00	

TABLE 5 Results of two-way ANOVAs for fencing (fence line versus interior) and plant traits

	Model term	df	F	P
Growth Form	Fencing	1	0.48	.49
	Growth Form	2	511.97	<.001
	Fencing * growth form	2	4.81	.009
Duration	Fencing	1	0.58	.45
	Duration	2	226.36	<.001
	Fencing * duration	2	0.58	.56
Origin	Fencing	1	0.61	.43
	Origin	1	229.69	<.001
	Fencing * origin	1	6.93	.01

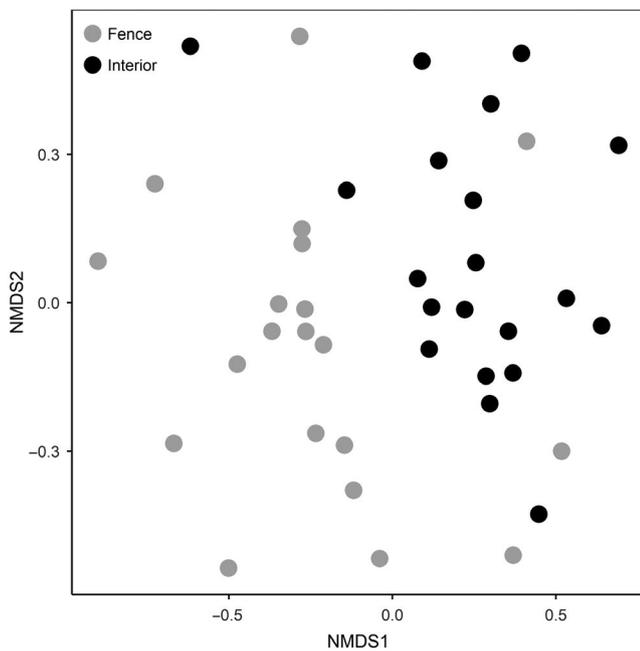


FIGURE 4 NMDS plot of plant communities found in vacant lots along fence lines (dark gray) versus lot interiors (black). Distances are based on Bray–Curtis similarity. Total NMDS stress was 0.21

“Growth form” includes forbs, graminoids, and woody species, “Duration” includes annual, biennial, and perennial species, and “Origin” includes native and introduced species. All models use species richness as a response variable between origin (native versus introduced) or growth form (graminoid versus woody versus forb) in lot interiors and along fence lines separately.

^aSignificant P values (at $\alpha = .05$) are denoted in bold.

other urban greening paradigms that emphasize the importance of native species (Tallamy, 2009; Aronson et al., 2017), the financial constraints of vacant lots suggest that allowing plant communities to develop spontaneously may be the best way to maximize urban ecosystem services (Gaertner et al., 2017).

It is worth recognizing that woody growth along fence lines may represent a conflict between ecological value of habitat and the social value of clean lines and cues-to-care (Nassauer, 1995). This juxtaposition of social and ecological values and the trade-offs between them is worth further investigation, specifically in relation to management of urban land types (Anderson & Minor, 2019). Ultimately, to provide management advice that contributes to successful outcomes, we need to better understand the social contexts of fencing and mowing, as motivations for these practices

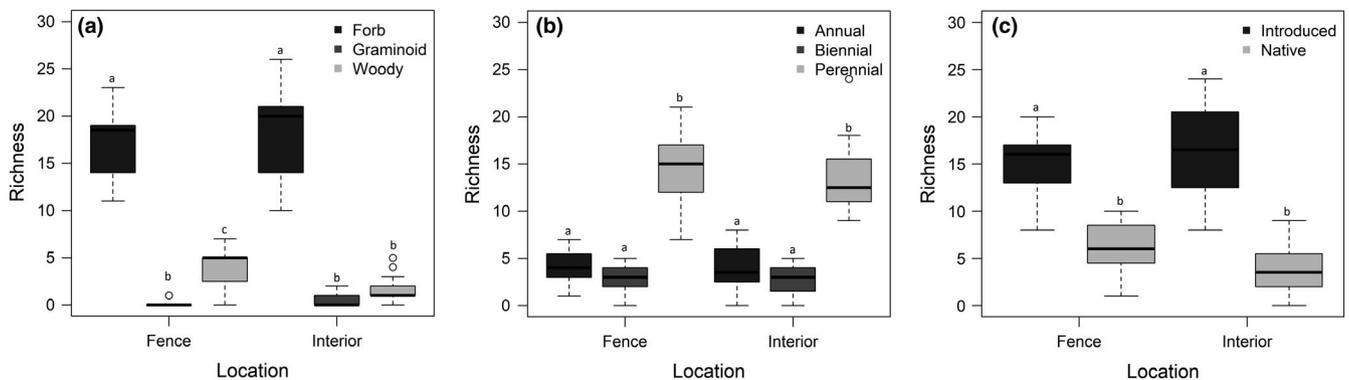


FIGURE 5 Functional composition of vegetation in lot interiors based on location within a vacant lot, within 0.5 m of a fence (fence line) or in the lot interior. Different letters represent significantly different groups based on Tukey’s HSD pairwise comparisons at $\alpha = 0.05$. When there was a significant interaction (origin and growth form), Tukey’s HSD was calculated manually using simple main effects. This allowed us to focus on the differences

are not biological in nature. Instead, they represent attempts to conform to social norms, meet legal regulations, or control behaviors and perceptions. Conservation and management strategies that seek to promote high-quality and heterogeneous plant communities and habitats in vacant lots must therefore be based on a firm understanding of ecological and social principals coupled with deliberate socio-environmental goal setting and community-minded execution.

A limitation of this work is that our mowing data were limited to 11 years of digitized records from a FOIA request. These data may not fully describe what happens in vacant lots. For example, the data do not indicate whether clippings were left on-site or removed. While we observed mulched clippings in some recently-mowed vacant lots, we were unable to examine the effects of this practice, which other studies have found to be important in nitrogen cycling and plant community dynamics (Maron & Jeffries, 2001; Kopp & Guillard, 2002; Schippers & Joenje, 2002; Qian et al., 2003; Jakobsen et al., 2018). Furthermore, an examination of urban soils and the characteristics shaping the below-ground biotic and abiotic profiles of the area is necessary to truly understand the drivers of plant diversity in vacant lots. There are also social factors that were unaccounted for in our mowing data. It is possible that some neighbors take action on adjacent properties to improve the quality and aesthetics of their block, and city records may therefore underestimate actual mowing events. This could also be a potential confounding factor when assessing the independence of mowing and fencing, as some neighbors fence and maintain surrogate yards in adjacent vacant space — a process known as “blotting” (Stewart et al., 2019). While retrospective studies are valuable, controlled, factorial experiments are the best way to thoroughly understand how mowing affects plant communities across a landscape.

Vacant lots are unique because city-wide management is often the responsibility of one department. Given these socio-ecological complexities, management protocols should be goal-oriented and based on science-informed best practices specific to vacant lots. Urban areas may not respond to management in the same ways as non-urban land. We caution that vacant-lot management should not be treated as an extension of management in other land types or approached with a one-size-fits-all protocol. Instead, understanding how certain elements of management shape plant communities can promote a more tailored approach that balances social and ecological needs and benefits.

AUTHOR CONTRIBUTIONS

EA and EM conceived of this project and analysis collaboratively as part of EA's dissertation. EA completed the field work, analysis, and writing, with significant guidance by EM. EM also provided substantive review of the manuscript throughout the review process.

DATA AVAILABILITY STATEMENT

All data used in this analysis have been included in the supplemental information accompanying this publication.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

Appendix S1. Associations of all identified species with mowing cluster (infrequent versus intensive) and location (fence line versus interior)

Appendix S2. Elbow method graph indicating number of clusters for mowing analysis

Appendix S3. Means and standard deviations for species richness across functional groups in: (a) intensively and infrequently mowed lot interiors; and (b) along fence lines and in lot interiors

Appendix S4. Metadata for relevant data sets

Appendix S5. Fence line community presence/absence raw data

Appendix S6. Interior community presence absence raw data

Appendix S7. Mowing data from FOIA request

Appendix S8. Site matrix with environmental variables and locations

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