Plant communities in Chicago residential neighborhoods show distinct spatial patterns

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ABSTRACT

Residential yards and gardens can have surprisingly high plant diversity. However, we still do not understand all the factors that drive diversity in individual gardens, or how gardens scale up to create larger patterns of urban biodiversity. For example, social interactions between neighbors could affect whether they mimic each other's yard design, affecting spatial turnover in plant communities. Further, socio-economic differences between neighborhoods might result in distinct plant assemblages across a city. In this paper, we used fieldwork, GIS, and spatial statistics to examine the variability in front yard vegetation—both cultivated and spontaneous plants—in 870 yards in Chicago, Illinois (USA). Our goals were to understand diversity and spatial patterning of plant communities in residential neighborhoods and how they vary with scale, considering alpha, beta, and gamma diversity. We addressed the following questions: (1) How do alpha, beta, and gamma diversity of cultivated and spontaneous plants vary between neighborhoods with different socioeconomic characteristics? (2) Within neighborhoods, do we see spatial autocorrelation in front-yard plant communities? If so, do those spatial patterns affect plant diversity at the neighborhood scale? We found diverse plant communities and distinct spatial patterns across Chicago. Richness and composition of both spontaneous and cultivated plants differed between neighborhoods, with some differences explained by socioeconomic factors such as education. Spontaneous and cultivated plants showed significant spatial autocorrelation, although that spatial autocorrelation generally did not influence neighborhood-scale diversity. Knowledge of these spatial patterns and their socioeconomic drivers could be exploited to increase adoption of environmentally-friendly yard management practices across a city.

1. Introduction

As urban areas grow in number and extent, urban plant diversity is becoming more important to understand and preserve. Urban plant communities provide ecosystem services to urban residents (Schwarz et al., 2017) and habitat for many species of wildlife (Barth et al., 2015; Hülsmann et al., 2015). For some taxa, like pollinating insects, diverse urban plant communities may be key to their conservation (Hall et al.,

2017). Residential land may be especially important for plant diversity, as the amount of land and vegetation in private yards and gardens is often greater than the amount preserved as urban open space (González-García & Sal, 2008; Lin et al., 2015; Ossola et al., 2019). However, despite their high variability, residential areas are less well-studied than other types of urban land use because of challenges in accessing private land.

Studies of residential neighborhoods show that yards and gardens

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can have surprisingly high plant diversity. Seven hundred and fifty-six plant species were recorded in 133 private yards in Minnesota, USA (Cavender-Bares et al., 2020), while 553 woody plant species were recorded in only 55 gardens in New Zealand (van Heezik et al., 2013). In a study of seven North American cities, yards had more plant species than nearby natural areas (Padullés Cubino et al., 2019). The majority of these species are cultivated species that were planted intentionally by residents, although most yards have some spontaneously-occurring species too. The factors that promote spontaneous species are likely to differ from those that promote cultivated species (Cavender-Bares et al., 2020). In particular, spontaneous species may be subject to stronger environmental filtering and species interactions while human interference can reduce these pressures on cultivated species through soil improvements, pest removal, and other management actions.

Understanding the drivers of plant diversity in residential neighborhoods is challenging because of social factors that operate at different scales (Cook et al., 2012). One factor that is commonly invoked to explain yard vegetation is the "Luxury Effect," in which people with greater economic means inhabit landscapes with higher biodiversity (Hope et al., 2003). This pattern can be explained by various non-exclusive mechanisms, including (1) environmental gradients or government policies that create variation in neighborhood-scale biodiversity, with more biodiverse neighborhoods having higher property values (Grove et al., 2018; Schell et al., 2020), and (2) direct modifications to individual gardens that increase biodiversity, disproportionately enacted by households with greater economic means (Avolio et al., 2020; Blanchette et al., 2021; Kendal et al., 2012a; Padullés Cubino et al., 2019; van Heezik et al., 2014). A review of the luxury effect (Leong et al., 2018) showed that it is widespread but not universal, and tends to be most pronounced in arid regions and older neighborhoods. Upon proposing the luxury effect, Hope et al. (2003) hypothesized the association between household income and biodiversity could be due to correlated socioeconomic factors such as education, cultural values and institutional power. Several subsequent studies have shown a relationship between education level of residents and yard vegetation (Kendal et al., 2012a; Luck et al., 2009; Padullés Cubino et al., 2019; van Heezik et al., 2014).

Culture, social norms, and peer pressure also play a role in people's gardening decisions. For example, people from Mediterranean cultures are more likely to plant food plants while people from British cultures are more likely to plant shade trees (Fraser & Kenney, 2000). People often want their yards to conform to neighborhood norms (Nassauer et al., 2009), especially when they live on smaller parcels of land (Visscher et al., 2014). Social interactions and norms may motivate neighbors to influence or imitate each other when managing their yards, potentially leading to spatial contagion in yard vegetation (sometimes called 'mimicry') that has been observed in several cities (Hunter & Brown, 2012; Locke et al., 2021; Minor et al., 2016; Zmyslony & Gagnon, 2000).

Plant diversity in a city depends on diversity in yards and neighborhoods, but we still do not understand how local diversity scales up to create larger patterns of urban biodiversity (Swan et al., 2021). For example, at larger spatial scales, socio-economic differences between neighborhoods might result in distinct plant assemblages across different areas of a city. Conversely, within a single neighborhood, fine-scale patterns in yard vegetation may be attributed to other kinds of factors. For example, social interactions between neighbors could affect the strength of social norms and the degree to which neighbors mimic each other's yard design, creating spatial autocorrelation among adjacent yards. Mimicry between neighbors could not only alter plant community diversity within yards ("alpha diversity"), but also reduce variation in species composition between yards (i.e., spatial turnover or "beta diversity"), limiting plant diversity at larger scales ("gamma diversity"). Thus, fine-scale social drivers could potentially affect larger-scale ecological patterns. Few, if any, empirical studies have considered yard diversity or its drivers at multiple scales simultaneously, and

Swan et al. (2021) assert that studying beta diversity in particular should produce unique insights about urban biodiversity.

In this paper, we examined the variability in front yard vegetation—both cultivated and spontaneous plants—in 870 front yards distributed across 16 neighborhoods in Chicago, Illinois (USA). Our goals were to understand composition and spatial patterns of plant communities in residential front yards and how they vary with scale. We address the following research questions:

(1) How do alpha, beta, and gamma diversity of cultivated and spontaneous plants vary between neighborhoods with different socioeconomic characteristics? How does plant species composition vary between those same neighborhoods? Do we see evidence of the luxury effect or other socio-economic drivers?

(2) Within neighborhoods, do we see spatial autocorrelation in front-yard plant communities? If so, do those spatial patterns affect alpha, beta, or gamma diversity of plants?

We predicted that cultivated species would be more closely linked with socioeconomic characteristics than spontaneous species, and that neighborhoods with significant spatial autocorrelation would have reduced beta and gamma diversity.

2. Methods

2.1. Study area

This study took place in Chicago, IL (USA), the third largest city in the United States by population. Chicago has a continental climate, with cold winters, warm summers, and moderate annual precipitation. The eastern border of the city is formed by Lake Michigan, one of the largest freshwater lakes in the world. The region lies at the interface of the deciduous forest biome of the eastern US and the tallgrass prairie biome of the Midwestern US.

Chicago has a human population of almost 2.7 million residents. The population of the city is diverse, with similar numbers of residents who identify as white alone (not Hispanic or Latinx), Black or African American, and Hispanic or Latinx. However, with some exceptions, most neighborhoods are extremely segregated and have relatively homogeneous populations in terms of race and ethnicity (Davis et al., 2012).

The houses in Chicago in general, and in our study neighborhoods in particular, are quite old; according to data from the US Census Bureau, most homes were built before 1939. The standard residential parcel in Chicago is 25 ft (7.6 m) × 125 ft (38.1 m), but there is some variation between parcels and neighborhoods and some homes are built on double lots. The approximate distance between the sidewalk and house (i.e., the depth of the front yard) is <10 m, although this also varies between parcels and neighborhoods. Neighborhoods in Chicago are not governed by homeowners' associations.

2.2. Data collection – the plant community

We selected 16 neighborhoods for our study sites. Neighborhoods were selected to cover a wide range of racial composition and income. Each neighborhood included two adjacent city blocks that were dominated by single-family homes and had houses on both sides of the street. Pairs of neighborhoods were clustered to facilitate fieldwork, although each neighborhood was at least 0.7 km from any other neighborhood.

Within each neighborhood, we sampled approximately 50 front yards (median = 50, min = 49, max = 79). Here we consider 'yards' to be the vegetated area in front of a home, including turfgrass, vegetable and flower beds, and woody species. We sampled yards in front of single-, two-, and three-family homes. Yards in front of abandoned houses (e.g., houses with boards on the windows) and yards in front of apartment buildings were excluded from the study; the remaining yards were sampled consecutively as we moved along the sidewalk. Yards were

Table 1

Summaries of socio-economic predictor variables for each neighborhood. All variables except mean parcel size and number of yards per neighborhood were extracted from the US Census Bureau, at the scale of block groups.

Predictor variable	Median	Mean	Range	Std. Dev.
% of residents under age 18	26.0	24.5	7.0–35.7	7.9
Median age of residents (years)	33.7	35.5	26.8–49.6	7.3
% of residents with a Bachelors degree	17.6	26.5	2.6–69.9	23.7
% of residents who identify as White	19.9	36.4	0–89.7	35.6
% of residents who identify as Black or African American	2.2	24.7	0–100	41.3
% of residents who identify as Asian	3.5	3.5	0–8.7	3.3
% of residents who identify as Hispanic/Latinx	15.8	34.1	0–96.6	36.2
% of homes that are renter occupied	40.2	44.2	17.4–73.1	18.7
Median household income (1000 s of US$)	48.3	62.5	20.1–171.0	37,260
Mean parcel size (m^2)	351.1	374.8	270.5–1198.6	81.9
Number of sampled yards per neighborhood	50	54.4	49–79	8.9

surveyed from June to August of 2015.

In each sampled front yard, we recorded the presence of all plant species excluding turf grasses. We surveyed both the main yard, directly in front of the house, and the "parkway", which is the narrow strip of land (usually vegetated) between the sidewalk and the street. The city owns the rights-of-way to the parkway, and plants street trees on this land, but the homeowner is responsible for managing other vegetation on the land.

Plant species growing in yards were classified as 'cultivated' or 'spontaneous'. Cultivated plants included any mature plant that was growing in a garden bed and could have been purchased from a plant nursery (i.e., ornamental and landscaping plants). Spontaneous plants included plants commonly considered 'weeds' by herbicide companies and gardening guides, and any non-turfgrass plant (cultivated or spontaneous) growing in the middle of turfgrass. Mature trees were always considered as cultivated but tree seedlings were considered to be spontaneous. A plant species could potentially be classified as cultivated in some cases (e.g., a large maple tree) and spontaneous in others (e.g., a maple seedling growing in the middle of a garden bed).

Each observed plant was recorded and identified to species whenever possible, using photos for later reference if the plant could not be identified in the field. Plants with a large number of horticultural cultivars and varieties (e.g., roses) were typically identified to genus only, as were a small group of genera for which identification to the species level was too difficult without collecting samples. We separately recorded and identified any street trees growing in the parkway, but these were excluded from analysis as they are outside the control of residents.

2.3. Data collection – socio-economic and GIS variables

We georeferenced the address of each sampled yard in ArcGIS 10.5 and linked them to cadastral data obtained from the city. We used the cadastral data to measure the size of individual parcels containing each yard. We also downloaded census block group polygons from the U.S. Census Bureau, which allowed us to extract socio-economic information specific to each neighborhood. Half of the sampled neighborhoods spanned two block groups, so we used the mean values from the two block groups. No two neighborhoods were in the same block group.

We extracted the following socio-economic variables for each neighborhood, which are summarized in Table 1: median household income (called 'income' from here forward), median age of residents ('age'), percent of residents under age 18 ('% children'), percent of

residents renting their home ('% renters'), percent of residents with a Bachelor's degree ('education'), and percent of residents who self-identified as white, Black or African-American, Hispanic, or Asian. Several pairs of socio-economic variables were correlated with each other (Appendix A).

2.4. Analyses

Our data analysis was conducted at multiple spatial scales. First, at the neighborhood scale, we examined the impact of socioeconomic factors on alpha, beta, and gamma diversity and community composition (Question 1). Second, at the scale of individual yards, we examined finer-scale patterns in spatial autocorrelation within each neighborhood (Question 2). Socioeconomic data were only available at the neighborhood (i.e., census block group) scale, thus we could not detect the importance of socioeconomic factors at the scale of individual parcels.

(1) How do alpha, beta, and gamma diversity of cultivated and spontaneous plants vary between neighborhoods with different socioeconomic characteristics? How does plant species composition vary between those same neighborhoods? Do we see evidence of the luxury effect or other socio-economic drivers?

To evaluate differences between neighborhoods, we first calculated alpha diversity, beta diversity, and gamma diversity for each neighborhood. Cultivated and spontaneous species were considered separately in each case. Alpha diversity was the mean number of species per yard, gamma diversity was the cumulative number of species per neighborhood, and beta diversity was turnover in species composition between yards, measured as multiple-site Sorenson (multiplicative beta diversity [gamma divided by mean alpha] standardized by number of sites; Chao et al., 2012). All data analysis was performed using R (R Core Team, 2019).

To evaluate the effect of socioeconomic factors on the alpha, beta, and gamma diversity of cultivated and spontaneous species, we used linear or generalized linear regression models, depending on the error distribution of the diversity measure. All diversity measures were modeled using linear regression except for the gamma diversity of spontaneous species, which was better modelled using a log linked generalized linear Poisson regression. We used a model selection approach to identify the best models for each diversity measure. All socioeconomic predictors were included in the global model for each response, but to avoid multicollinearity between predictors we used model subsetting to exclude any models with correlated predictor variables (Pearson rho > 0.5) from the model ranking. In addition to socioeconomic variables, the global models for alpha, beta, and gamma diversity included the mean parcel size for each neighborhood as a potential predictor variable, and the global models for gamma diversity also included the number of yards in each neighborhood. We ranked all candidate models using AICc scores, calculated with the 'MuMIn' package in R (Barton, 2020). We identified the top model set as models within 2 AICc scores (ΔAICc $\leq$ 2) of the top model. For each model included in the top model set, we tested for spatial autocorrelation of residuals with Moran's I using the 'spdep' package in R (Bivand & Wong, 2018).

To evaluate socio-economic drivers of plant community composition in front yards, we used distance-based redundancy analysis (dbRDA). First, we calculated differences in species composition between yards and between neighborhoods. We measured differences with pairwise Sørenson dissimilarity, using the "vegdist" function in the "vegan" package in R (Oksanen et al., 2020). We excluded species that occurred in only a single yard (for between-yard dissimilarity) or a single neighborhood (for between-neighborhood dissimilarity) from these calculations, as recommended to reduce statistical 'noise' in the dataset (McCune & Grace, 2002). We then used the "capscale" function in the "vegan" package in R to fit the dbRDAs, using pairwise Sorenson dissimilarity (including all species present in at least two neighborhoods) as a measure of difference in species composition across
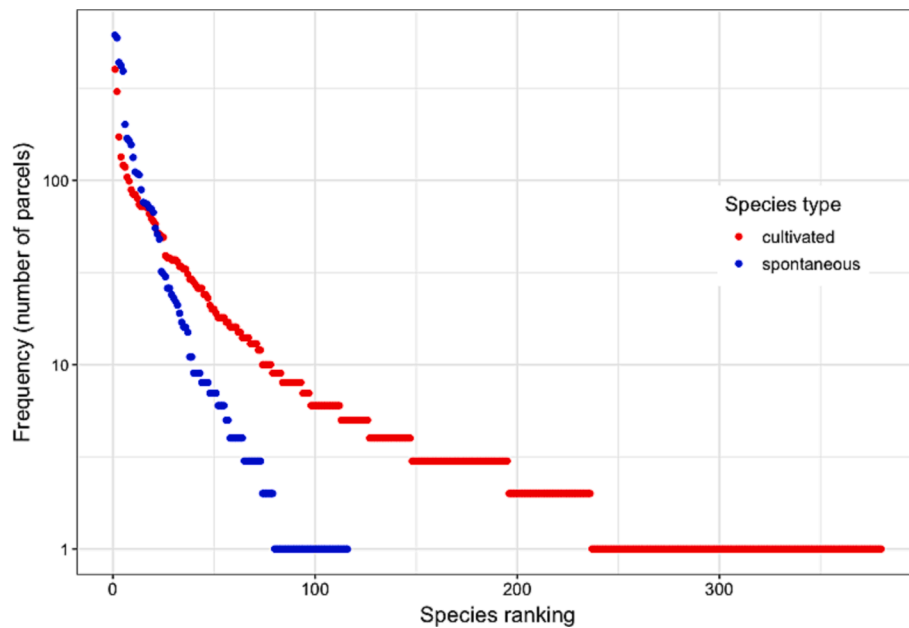
Fig. 1. Rank abundance curves showing the frequency distributions of cultivated and spontaneous species across the dataset. Seven of the ten most common species were spontaneous, while most cultivated species were found in only one yard. Note that the y-axis has a logarithmic scale.
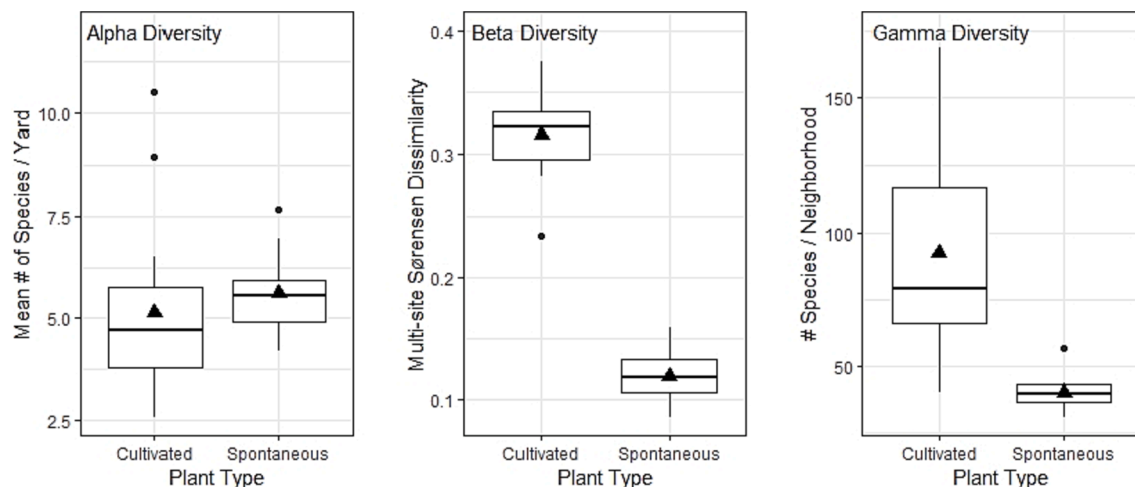
Fig. 2. Alpha, beta, and gamma diversity for cultivated and spontaneous plant species in 16 Chicago neighborhoods. Horizontal line inside box indicates the median value and triangle indicates the mean value.

neighborhoods. We used a similar model selection approach to that used for diversity models, comparing all possible models except those with correlated predictors, and selecting the model with the highest R^2 value.

(2) Within neighborhoods, do we see spatial autocorrelation in front-yard plant communities? If so, do those spatial patterns affect alpha, beta, or gamma diversity of plants?

Looking at individual yards in each neighborhood, we tested for spatial autocorrelation in four measures of front yard vegetation: richness (alpha diversity) of cultivated species, richness of spontaneous species, community composition of cultivated species, and community composition of spontaneous species. Community composition was compared between yards with the Sorenson similarity measure (1 - Sorenson dissimilarity). Spatial autocorrelation in richness was assessed with Moran's I and community composition was assessed with Mantel tests.

To evaluate spatial autocorrelation, we needed a measure of distance between individual yards. Because the average width of parcels varied between homes and neighborhoods, and we did not want difference in

parcel size to obscure the influence of neighbors, we used an approach similar to Zmyslony & Gagnon (2000) and Minor et al. (2016). This method estimates the number of parcels between two yards rather than the Euclidean distance between them. We first defined parcel centroids using the "gCentroid" function from the "rgeos" package in R (Bivand et al., 2021). We then calculated pairwise distances between parcels in the same neighborhood with the "gDistance" function from the "rgeos" package, identified the nearest neighbor distance for each parcel, and calculated the mean nearest neighbor distance for each neighborhood. Finally, we estimated the number of parcels separating each pair of yards by dividing the Euclidean distance between each pair by the mean nearest neighbor distance for that neighborhood. We considered yards to be one parcel apart if they were either directly adjacent or across the street from one another, two parcels apart if they were separated by one parcel between them or diagonally across from each other, and so on. We did not calculate distance between yards in different neighborhoods.

We evaluated patterns of spatial autocorrelation in plant diversity at different distance classes, to identify the specific distances at which
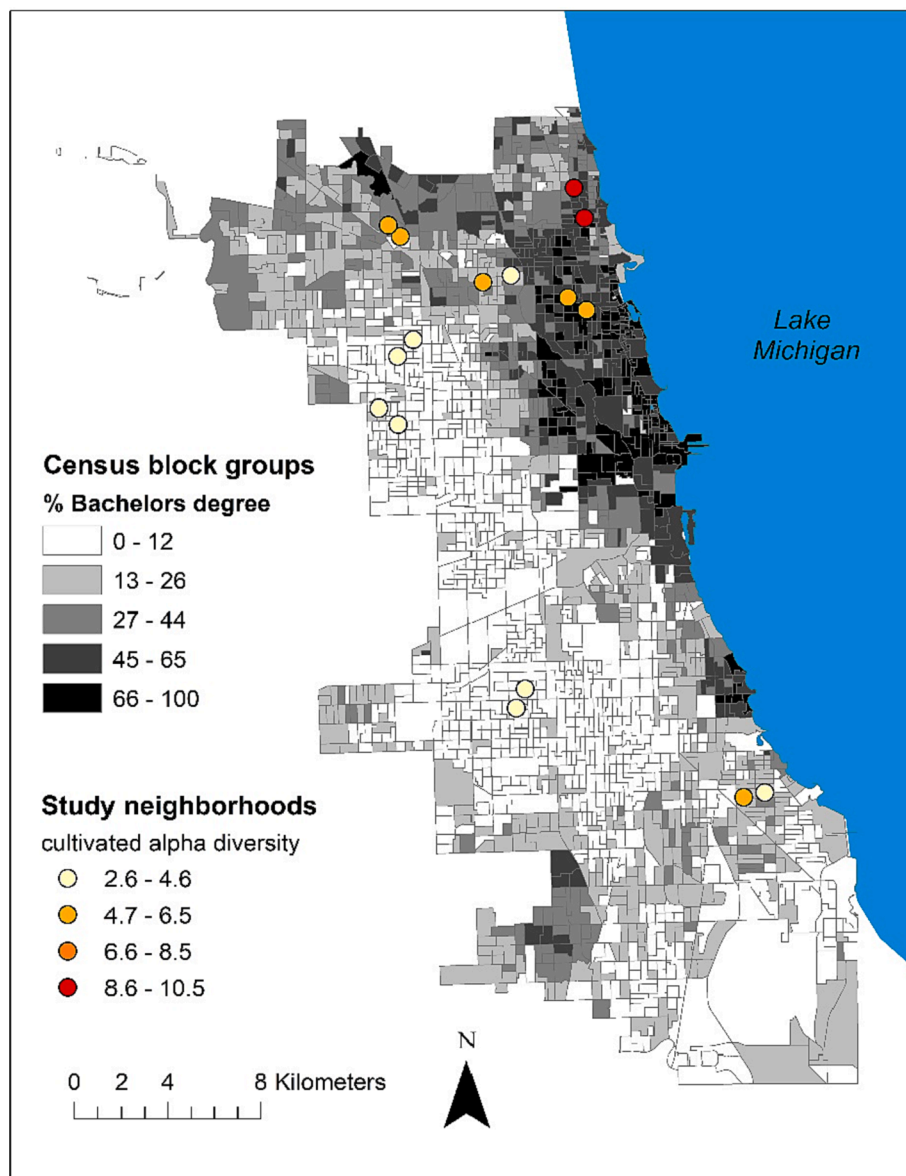
Fig. 3. Map of study neighborhoods in Chicago. Cultivated alpha diversity, the mean number of intentionally-planted species per yard in each neighborhood, was positively related to the education of residents.

spatial patterns occur. We did this by comparing yards at different distances from one another, using the number of parcels separating yards (ranging from 1 to 42 parcels) as distance classes. All yards in the dataset were included in this analysis, regardless of neighborhood, to provide a large sample size. For alpha diversity of cultivated and spontaneous species, we calculated Moran's I using the "ape" package in R. For community composition, we calculated Mantel's R using the Pearson correlation method in the "vegan" package in R. We used correlograms to visually compare spatial autocorrelation trends across distances up to 30 parcels apart, as the sample size decreased substantially beyond that distance. We tested for significance of spatial autocorrelation using p-values from data permutations with progressive Bonferroni corrections (Legendre & Legendre, 2012).

Finally, to examine the effect of spatial autocorrelation on alpha, beta, and gamma diversity, we calculated a global measure of Moran's I and Mantel's R for each neighborhood individually. The global test provides a single measure of spatial autocorrelation (independent of distance class) for each neighborhood. This test allowed us to identify the specific neighborhoods in which spatial autocorrelation occurs, and

examine whether spatial autocorrelation between individual yards affected plant diversity (i.e., alpha, beta, or gamma diversity) at neighborhood scales. We used t-tests to compare neighborhoods with significant spatial autocorrelation to neighborhoods without significant spatial autocorrelation in terms of their alpha, beta, and gamma diversity. Due to the uneven sample size between neighborhoods with and without significant spatial autocorrelation, we supplemented this analysis with Spearman rank correlations between the measures of global spatial autocorrelation and the measures of alpha, beta, and gamma diversity.

3. Results

In total, we collected data from 870 front yards. While we did not measure yard size, based on knowledge of the standard parcel size and front yard shape we estimate that the total area surveyed was <7 ha. We observed 443 plant species across all yards. Twenty-seven plants were not identified to species or genus. Three hundred twenty-seven species were classified as cultivated, 63 species were classified as spontaneous,
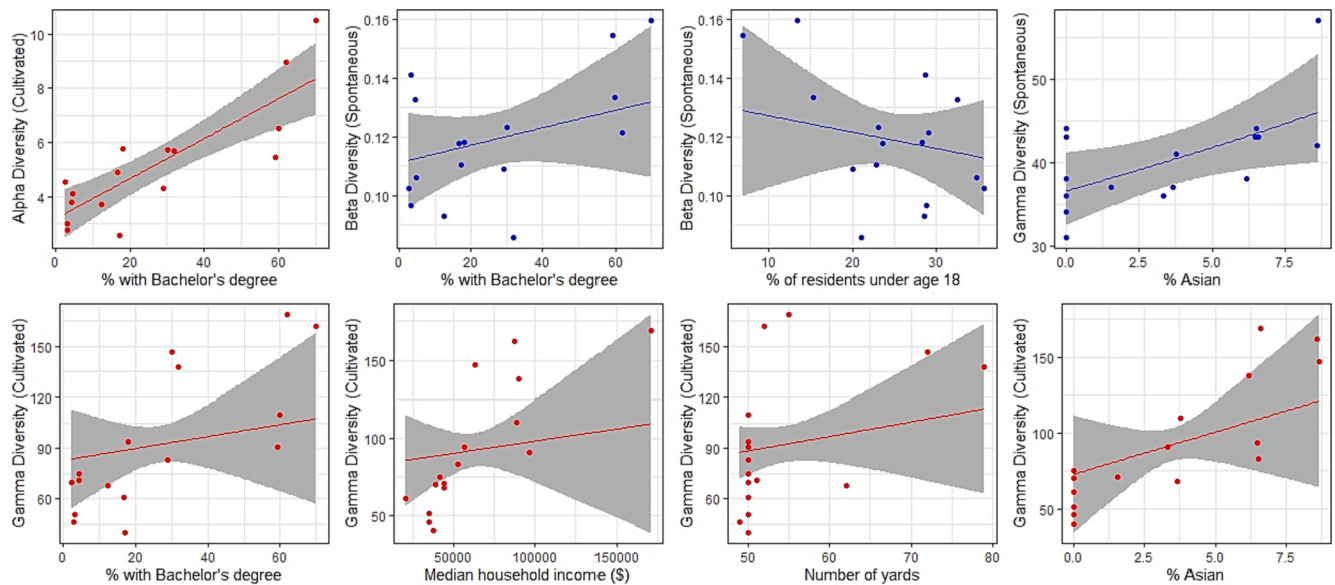
Fig. 4. Significant socio-economic predictors of cultivated and spontaneous plant diversity in 16 Chicago residential neighborhoods. The top row shows alpha diversity of cultivated plants, beta diversity of spontaneous plants, and gamma diversity of spontaneous plants; the bottom row shows gamma diversity of cultivated plants. Predictor variables shown here were in the top model set (AICc ≤ 2) for each diversity measure and had p values <0.05; full model details are shown in Tables 2-4. Figures show the effect of the specific variable with all other variables held constant at their mean value, predicted over the range of that variable in the dataset. The grey area represents the 95 % confidence interval of the predicted response.

and 53 species were classified as both cultivated and spontaneous (Appendix B). One hundred forty-four cultivated and 37 spontaneous species were only found in a single yard (Fig. 1); these were excluded from analysis related to species composition.

The alpha diversity of cultivated and spontaneous species was similar (Fig. 2). However, the gamma diversity of cultivated species greatly outnumbered spontaneous species. Similarly, beta diversity (multi-site Sorenson) was higher for cultivated species than spontaneous species. Across all yards, the four most common plants were all spontaneous species: *Taraxacum officinale* (dandelion, n = 613 front yards), *Plantago major* (broadleaf plantain, n = 593), *Oxalis stricta* (yellow woodsorrel, n = 436), and *Viola sororia* (blue violet, n = 419). The fifth most common species was cultivated: *Hosta fortunei* (hosta, n = 400). A list of all observed species is provided in Appendix B.

(1) How do alpha, beta, and gamma diversity of cultivated and spontaneous plants vary between neighborhoods with different socioeconomic characteristics? How does plant species composition vary between those same neighborhoods? Do we see evidence of the luxury effect or other socioeconomic drivers?

For cultivated species, the socio-economic models of alpha and gamma diversity had relatively high explanatory power (adjusted R^2 of 0.68 and 0.71, respectively). At both scales, cultivated plant species richness was higher in neighborhoods with more college-educated residents (Figs. 3 and 4, Tables 2 and 3). Gamma diversity of cultivated plants was also higher in neighborhoods with higher household income, more Asian residents, and more sampled yards (Fig. 4, Table 3). No socio-economic variables significantly explained beta diversity of cultivated species (Table 4).

For spontaneous species, the socio-economic models had lower explanatory power. No socio-economic variables significantly explained alpha diversity of spontaneous species (Table 2). Gamma diversity of spontaneous species was higher in neighborhoods with more Asian residents (Table 3). Neighborhoods with more children had lower beta diversity of spontaneous species, and neighborhoods with more college-educated residents had higher beta diversity (Table 4). Note that low explanatory power of socioeconomic variables does not suggest that spontaneous plant species were uniformly distributed across the landscape, as generalized linear models and PERMANOVA indicated that

spontaneous plant communities differed significantly between neighborhoods (Appendix C). There was no spatial autocorrelation in residuals of any models included in the top model set, indicating that the models correctly accounted for any spatial dependencies.

The composition of cultivated species composition across neighborhoods was best explained by the percent of Black residents, the percent of renters, and the percent of residents with Bachelor's degrees (adjusted R^2 = 0.30, p = 0.001; Table 5) and the composition of spontaneous species was best explained by the percent of Black residents, the percent of renters, median household income, and percent of residents under the age of 18 (R^2 = 0.17, p = 0.004).

(2) Within neighborhoods, do we see spatial autocorrelation in front-yard plant communities? If so, do those spatial patterns affect alpha, beta, or gamma diversity of plants?

Including data from all yards and neighborhoods, Moran's I tests indicated significant spatial autocorrelation at consecutive distance classes up to 22 yards apart for richness of cultivated species and 3 yards apart for richness of spontaneous species (Fig. 5A). Mantel tests indicated significant spatial autocorrelation up to 10 parcels apart for composition of cultivated species and 26 parcels apart for composition of spontaneous species (Fig. 5B).

When neighborhoods were examined individually for global spatial autocorrelation, we detected significant patterns in some neighborhoods and not in others (Appendix D). Two neighborhoods showed significant spatial autocorrelation in the number of cultivated species and six in the number of spontaneous species. Only one neighborhood showed significant spatial autocorrelation in composition of cultivated species composition, while five did in composition of spontaneous species. Five neighborhoods did not show significant spatial autocorrelation for any vegetation characteristics (Appendix D).

In general, the t-tests showed no differences in alpha, beta, or gamma diversity between neighborhoods with spatial autocorrelation and those without. However, the five neighborhoods with spatial autocorrelation in spontaneous species composition also had lower beta diversity of spontaneous species (t = 2.84, p = 0.016; Fig. 6). The Spearman rank correlations confirmed the significant relationship between Mantel's r of spontaneous species and beta diversity of cultivated species (ρ = -0.52, p = 0.04); no other correlations were significant.

Table 2

Results of model selection for alpha diversity (mean # of species per yard, as measured at the neighborhood scale) of cultivated and spontaneous plant species in 16 Chicago neighborhoods. Linear models were used for all response variables. Models in the 'top' model set, as defined by any model within AICc $\leq$ 2 of the top model, are shown with their coefficients and standard error. * $p < 0.05$, † $p < 0.01$, ‡ $p < 0.001$.

	Intercept	% Children	Age	Education	% White	% Black	% Asian	% Hispanic	% Renter	Income	# of yards	Parcel size	AICc	ΔAICc	Aikake Weight	Adjusted R²
Cultivated plant alpha diversity																
Model 1	5.14‡ (0.30)			1.80‡ (0.31)									57.71	0	0.72	0.68
Model 2	5.14‡ (0.30)			1.63‡ (0.34)		−0.41 (0.34)							59.44	1.93	0.28	0.69
Spontaneous plant alpha diversity																
Model 1	5.60‡ (0.22)												45.69	0	0.27	NA
Model 2	5.60‡ (0.21)	0.35 (0.22)											46.02	0.33	0.23	0.10
Model 3	5.60‡ (0.21)			−0.35 (0.22)									46.07	0.38	0.22	0.09
Model 4	5.60‡ (0.22)				−0.32 (0.22)								46.59	0.90	0.17	0.06
Model 5	5.60‡ (0.22)								−0.26 (0.22)				47.31	1.62	0.12	0.02

Table 3

Results of model selection for gamma diversity (cumulative number of species per neighborhood) of cultivated and spontaneous plant species in 16 Chicago neighborhoods. Cultivated species were modeled with linear models, while spontaneous species required log-linked generalized linear Poisson regression models (R² for spontaneous species was McFadden pseudo R²). Models in the 'top' model set, as defined by any model within AICc $\leq$ 2 of the top model, are shown with their coefficients and standard error. * $p < 0.05$, † $p < 0.01$, ‡ $p < 0.001$.

	Intercept	% Children	Age	Education	% White	% Black	% Asian	% Hispanic	% Renter	Income	# of yards	Parcel size	AICc	ΔAICc	Aikake Weight	Adjusted R²
Cultivated plant gamma diversity																
Model 1	92.25‡ (5.56)						35.31‡ (5.75)						150.54	0	0.52	0.71
Model 2	92.25‡ (5.56)			29.77‡ (5.56)							17.75† (5.56)		151.78	1.24	0.28	0.73
Model 3	92.25‡ (5.48)									30.15‡ (5.83)	13.65* (5.83)		152.54	2.00	0.19	0.72
Spontaneous plant gamma diversity																
Model 1	3.69‡ (0.04)						0.09* (0.04)						101.14	0	0.72	0.38
Model 2	3.69‡ (0.04)						0.09* (0.04)		−0.04 (0.04)				103.03	1.88	0.28	0.48

Table 4

Results of model selection for beta diversity (measured as multiple-site Sorenson) of cultivated and spontaneous plant species in 16 Chicago neighborhoods. Linear models were used for all response variables. Models in the 'top' model set, as defined by any model within AICc ≤ 2 of the top model, are shown with their coefficients and standard error. * $p < 0.05$, † $p < 0.01$, ‡ $p < 0.001$.

	Intercept	% Children	Age	% White	Education	% Black	% Asian	% Hispanic	% Renter	Income	# of yards	Parcel size	AICc	ΔAICc	Akaike Weight	Adjusted R^2
Cultivated plant beta diversity																
Model 1	0.32‡ (0.01)		−0.02 (0.01)										−60.06	0	0.68	0.19
Model 2	0.32‡ (0.01)												−58.60	1.46	0.32	NA
Spontaneous plant beta diversity																
Model 1	0.12‡ (0.00)				0.01* (0.00)								−76.80	0	0.44	0.25
Model 2	0.12‡ (0.00)	−0.01* (0.00)			0.01* (0.00)								−76.53	0.27	0.39	0.24
Model 3	0.12‡ (0.00)								0.01 (0.00)				−74.88	1.92	0.17	0.28

4. Discussion

4.1. Patterns and drivers of plant diversity in residential neighborhoods

We found a diverse plant community in Chicago neighborhoods, with 443 plant species in 870 small front yards. For the cultivated species, we can explain approximately 70 % of the variation in both alpha (garden scale) and gamma (neighborhood scale) diversity by the socioeconomic differences between neighborhoods. In particular, the percent of residents with a 4-year college education was a strong predictor and positively associated with the number of cultivated species at the yard and neighborhood scale. Education can cause individuals to behave in more environmentally-friendly ways (Meyer, 2015), which may extend to their gardening practices, although environmental concerns are not always predictive of yard care (Carrico et al., 2013). Education can also be correlated with income (r = 0.81 in our dataset) and thus the two variables can be difficult to tease apart. However, in the top models for alpha diversity of cultivated species, education was always selected over income. The percent of Black or African American residents was also an important variable in one model of alpha diversity. The models for gamma diversity of cultivated species are less conclusive, with education, income, and percent of Asian residents each selected once. Therefore, our results provide weak support for the luxury effect but stronger support for the importance of education and other cultural factors.

In contrast to cultivated species, alpha and gamma diversity of spontaneous species could not be predicted well with our socioeconomic variables. It may be that abundance of spontaneous species, rather than their richness, is more closely linked to socioeconomic factors. We did not measure plant abundance and thus could not test this idea. But as residents do not intentionally plant spontaneous species (by definition), it is also likely that spontaneous plants experience less pressure from social drivers than do cultivated plants. Some previous research supports this idea. For example, yards in different income and life stage groups were equally weedy in one city (Avolio et al., 2020), while spontaneous species richness was predicted better by yard size than socioeconomic factors in another city (Cavender-Bares et al., 2020). However, in a different study of residential yards in Chicago, income was significantly and negatively related to richness of blooming spontaneous plants (Lowenstein & Minor, 2016). As Lowenstein and Minor (2016) only recorded plants that were in bloom, it may be that wealthy residents will tolerate a few weeds for short periods of time as long as they do not flower.

The majority of the species we observed in residential yards were cultivated plants, presumably planted and maintained to some extent by the residents or owners of these homes. However, the average individual yard had a similar number of cultivated and spontaneous species. The high overall diversity of cultivated species therefore comes from the turnover in plant community composition from one yard to another, as observed in the higher beta diversity for cultivated species. The most common cultivated species—*Hosta fortunei*—only occurred in 46 % of yards, and the second most common—*Taxus* species—only occurred in 35 % of yards. One hundred and forty-four cultivated species were only observed in a single yard. In comparison to cultivated species, spontaneous species were generally more widespread. The two most common spontaneous species—*Taraxacum officinale* and *Plantago major*—occurred in 70 % and 68 % of yards, respectively. While 37 spontaneous species occurred in only one yard, many of these single occurrences were tree seedlings or species usually classified as cultivated and thus not typical "weeds". The higher beta diversity of cultivated species is likely due in part to the large species pool available from garden centers and plant nurseries (Cavender-Bares et al., 2020) and diverse preferences of residents (Goodness, 2018; Kendal et al., 2012b). Furthermore, residents value variety in their gardens (Blanchette et al., 2021), which may lead them to seek out unique plant species.

Composition of spontaneous and cultivated species was linked to

Table 5
The top distance-based redundancy analysis (dbRDA) model, as identified by the highest R^2 value, for composition of cultivated and spontaneous plant species in 16 Chicago neighborhoods. Predictor variables in the top model are marked with an 'X'.

|	% Children	Age	Education	% White	% Black	% Asian	% Hispanic	% Renter	Income	# of yards	Parcel size	R^2 of top model
Cultivated plant composition			X		X			X				0.30
Spontaneous plant composition	X				X			X	X			0.17
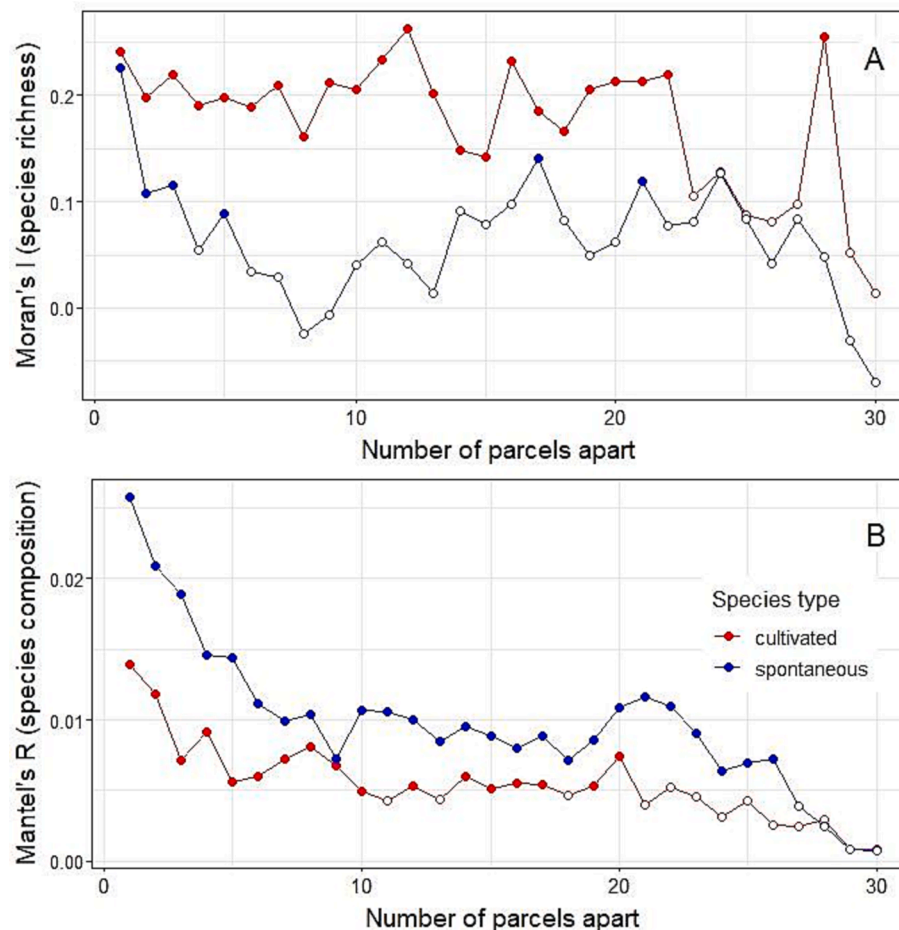
Fig. 5. Correlograms showing spatial autocorrelation between yards in intentional and spontaneous plant species richness (A) and composition (B) to thirty yards apart. Filled circles represent significant spatial autocorrelation between yards at that distance.

several socioeconomic variables—including the percent of residents who were Black or African American, and the percent of residents who were renters—but none of these variables explained a large amount of variation. The low explanatory power of the models is not surprising considering the large species pool available and the numerous unmeasured factors that could influence the community assembly in a particular neighborhood. For cultivated plants, these factors include availability of plants at the local nursery, preferences for specific plants by individual residents, local environmental conditions such as light availability, and biotic interactions such as herbivory (Avolio et al., 2021). Yard vegetation could also be related to the history of a neighborhood (Boone et al., 2010; Larson et al., 2017). Although all our study neighborhoods were first developed prior to 1939, some neighborhoods in Chicago have experienced redevelopment in subsequent decades that could have affected the plant community. Unfortunately, we do not have specific information about redevelopment for our neighborhoods. Finally, homeowners' associations can influence species composition in

some locations (Turner & Stiller, 2020) but are not a factor in our neighborhoods.

4.2. Spatial autocorrelation of vegetation in residential yards

We observed distinct spatial autocorrelation in the diversity and composition of yards within neighborhoods. Yards had similar numbers of cultivated species to their neighbors at surprisingly large scales, with high spatial autocorrelation observed between yards separated by more than 20 parcels. In contrast, spatial autocorrelation in richness of spontaneous species and composition of both cultivated and spontaneous species dropped off substantially within a few parcels' distance. It is likely that the spatial patterns in spontaneous species are caused primarily by ecological factors such as seed dispersal, which for many species rarely extends more than 10 m from the parent plant (Thomson et al., 2011; Vittoz & Engler, 2007). While seed dispersal may also play a role for cultivated species, especially if residents decide to keep
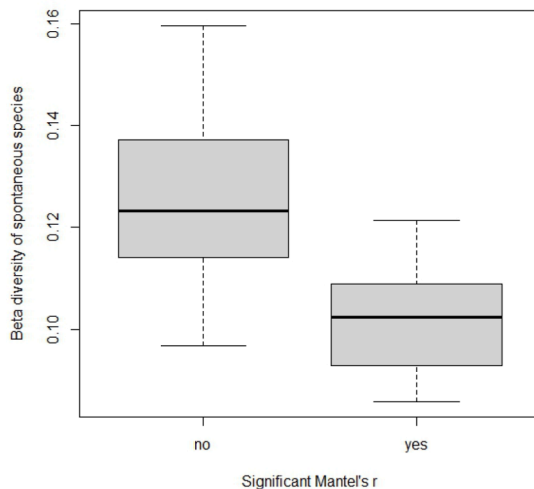
Fig. 6. Neighborhoods with significant spatial autocorrelation in composition of spontaneous species (n = 5), as measured with global Mantel's r, had lower beta diversity of spontaneous species compared to neighborhoods without spatial autocorrelation (n = 11).

attractive spontaneous plants in their gardens, mimicry between neighbors may help explain the observed spatial patterns in these plants. Research has shown that friends and neighbors can be the most important influence on gardening decisions (Goddard et al., 2013). For example, residents may attempt to imitate garden designs they see in their neighborhood (Uren et al., 2015). Similarly, neighbors with social ties may share plants or work together on their gardens (Lang, 2014) or share gardening information with each other (Martini et al., 2014), resulting in nearby gardens that are more similar than gardens that are farther away. Plants that are easy to propagate might be shared more frequently than other plants, and future research could examine whether certain plants show stronger spatial patterns than others.

In addition to mimicry behaviors, other social factors might create spatial autocorrelation in yard vegetation. For example, homeowners' associations rules, or use of the same landscaping companies or plant nurseries, could create similar vegetation in adjacent yards or more separated yards in the same neighborhood. However, these factors are likely to operate at different spatial scales than mimicry and may help explain the pattern of similar cultivated species richness in yards at broader (i.e., whole neighborhood) scales. By collecting information about individual residents at the parcel scale, future research could attempt to test whether spatial autocorrelation persists after statistically controlling for socioeconomic similarities between neighbors. Interviews of residents or long-term observations of neighborhoods could also help shed light on the factors that create the observed spatial patterns.

We expected that processes leading to spatial autocorrelation, such as neighbor mimicry, would lead to high similarity in yard vegetation (i. e., lower beta diversity) and fewer species overall (i.e., lower gamma diversity). However, spatial autocorrelation in plant communities was generally not associated with alpha, beta, or gamma diversity. The one exception was for beta diversity of spontaneous species, which was lower in neighborhoods with significant spatial autocorrelation in species composition. We can think of several possible reasons for the disconnect between spatial autocorrelation and beta diversity. First, neighborhood residents may share gardening ideas or plants with each other but not necessarily with their immediate next-door neighbors; this could create low beta diversity without spatial autocorrelation. Second, homeowner association rules could result in neighborhoods with mostly uniform yards, again leading to low beta diversity but no spatial auto-correlation. Conversely, if yards in a neighborhood were all very

different from each other, this could result in high beta diversity but no spatial autocorrelation. In terms of the relationship between spatial autocorrelation and gamma diversity, if mimicry causes residents to add plants to their yards to make them more similar to their neighbors' yards, but does not cause them to remove plants from their yards, this could create spatial autocorrelation without decreasing neighborhood-scale (gamma) diversity. Therefore, we suggest that the relationship between mimicry and biodiversity is complex, and different forms of mimicry could have different effects on large-scale patterns of biodiversity. The mechanisms by which small-scale social interactions affect larger-scale patterns in biodiversity warrant additional research.

4.3. Implications for conservation of urban biodiversity

Of the 443 plant species in our neighborhoods, only 14 % were consistently classified as spontaneous. Cultivated plants therefore form the base of the food chain for wildlife in these neighborhoods. While cultivated and ornamental plants don't always provide the same resources as native plant species, they can help support higher trophic levels (Baisden et al., 2018; Erickson et al., 2021; Mach & Potter, 2018; Ricker et al., 2019). In particular, urban pollinator diversity has been positively linked with garden plant diversity—including cultivated, spontaneous, native, and non-native species—in multiple studies (Gerner & Sargent, 2021; Lowenstein et al., 2014; Majewska & Altizer, 2020; Martins et al., 2017). Urban bird communities have also been linked to yard vegetation (Belaire et al., 2014; Lerman et al., 2021). These findings highlight the potential for residential neighborhoods to contribute to the conservation of diverse urban wildlife.

As proposed by others (Goddard et al., 2013; Locke et al., 2021), yard mimicry behaviors could be exploited to increase adoption of native plant gardens, certified wildlife habitats, or other environmentally-friendly yard management practices throughout neighborhoods. Exemplary gardens with environmental benefits could be 'seeded' in strategic locations to encourage their imitation and adoption (Hunter & Brown, 2012). Due to the often-linear forms of residential neighborhoods, gardens have the potential to form corridors through urban areas (Ossola et al., 2019; Rudd et al., 2002) that could connect larger nature preserves and facilitate migration of insects and birds across the urban landscape. Even without the formation of corridors, the spread of environmentally-friendly gardens would have numerous benefits for humans and wildlife alike (Cox & Gaston, 2018; Raymond et al., 2019; Widows & Drake, 2014). Mimicry behaviors should be further studied to understand where and why they occur and how we can exploit them to increase urban biodiversity.

5. Conclusions

This study is among the first to evaluate how yard-scale plant diversity and spatial patterns in residential plant communities scale up to create larger patterns of biodiversity. We found a diverse plant community with high turnover of cultivated species between yards. Alpha and gamma diversity of cultivated species were positively related to the education of neighborhood residents, but diversity of spontaneous species could not be predicted well with our measured socioeconomic variables. Richness and composition of both cultivated and spontaneous species showed significant spatial autocorrelation, with front yards that were closer together being more similar than yards that were far apart. However, spatial autocorrelation in plant communities did not generally influence alpha, beta, or gamma diversity. We suggest that the relationships between mimicry, spatial autocorrelation, and biodiversity are complex and warrant further research, as they could help planners and conservation biologists increase biodiversity in urban areas.

Declaration of Competing Interest

The authors declare that they have no known competing financial

interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104663.

References

Avolio, M., Blanchette, A., Sonti, N. F., & Locke, D. H. (2020). Time is not money: Income is more important than lifestage for explaining patterns of residential yard plant community structure and diversity in baltimore. *Frontiers in Ecology and Evolution, 8*, 85.

Avolio, M. L., Swan, C., Pataki, D. E., & Jenerette, G. D. (2021). Incorporating human behaviors into theories of urban community assembly and species coexistence. *Oikos, 130*, 1849–1864.

Baisden, E. C., Tallamy, D. W., Narango, D. L., & Boyle, E. (2018). Do cultivars of native plants support insect herbivores? *hortte, 28*, 596–606.

Barth, B., Ian FitzGibbon, S., & Wilson, R. (2015). New urban developments that retain more remnant trees have greater bird diversity. *Landscape and Urban Planning, 136*, 122–129.

Barton, K.: MuMIn: Multi-model inference. (2020).

Belaire, J. A., Whelan, C. J., & Minor, E. S. (2014). Having our yards and sharing them too: The collective effects of yards on native bird species in an urban landscape. *Ecological Applications, 24*, 2132–2143.

Bivand R, Rundel C, Pebesma E, *et al.* 2021. rgeos: Interface to Geometry Engine - Open Source ('GEOS'). R package version 0.5-2.

Bivand, R. S., & Wong, D. W. S. (2018). Comparing implementations of global and local indicators of spatial association. *TEST, 27*, 716–748.

Blanchette, A., Trammell, T. L. E., Pataki, D. E., et al. (2021). Plant biodiversity in residential yards is influenced by people's preferences for variety but limited by their income. *Landscape and Urban Planning, 214*, Article 104149.

Boone, C. G., Cadenasso, M. L., Grove, J. M., et al. (2010). Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: Why the 60s matter. *Urban Ecosystemem, 13*, 255–271.

Carrico, A. R., Fraser, J., & Bazuin, J. T. (2013). Green with envy: Psychological and social predictors of lawn fertilizer application. *Envir and Behavior, 45*, 427–454.

Cavender-Bares, J., Cubino, J. P., Pearse, W. D., et al. (2020). Horticultural availability and homeowner preferences drive plant diversity and composition in urban yards. *Ecological Applications, 30*, e02082.

Chao, A., Chiu, C., & Hsieh, T. (2012). Proposing a resolution to debates on diversity partitioning. *Ecology, 93*, 2037–2051.

Cook, E. M., Hall, S. J., & Larson, K. L. (2012). Residential landscapes as social-ecological systems: A synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosystem, 15*, 19–52.

Cox, D. T. C., & Gaston, K. J. (2018). Human–nature interactions and the consequences and drivers of provisioning wildlife. *Philosophical Transactions of the Royal Society B, 373*, 20170092.

Davis, A. Y., Belaire, J. A., Farfan, M. A., Milz, D., Sweeney, E. R., Loss, S. R., & Minor, E. S. (2012). Green infrastructure and bird diversity across an urban socioeconomic gradient. *Ecosphere, 3*, 105.

Erickson, E., Patch, H. M., & Grozinger, C. M. (2021). Herbaceous perennial ornamental plants can support complex pollinator communities. *Scientific Reports, 11*, 17352.

Fraser, E., & Kenney, W. A. (2000). Cultural background and landscape history as factors affecting perceptions of the urban forest. *Journal of Arboriculture, 26*, 106–113.

Gerner, E. E., & Sargent, R. D. (2021). Local plant richness predicts bee abundance and diversity in a study of urban residential yards. *Basic and Applied Ecology*. S1439179121001833.

Goddard, M. A., Dougill, A. J., & Benton, T. G. (2013). Why garden for wildlife? Social and ecological drivers, motivations and barriers for biodiversity management in residential landscapes. *Ecological Economics, 86*, 258–273.

González-García, A., & Sal, A. G. (2008). Private urban greenspaces or "patios" as a key element in the urban ecology of tropical Central America. *Human Ecology, 36*, 291.

Goodness, J. (2018). Urban landscaping choices and people's selection of plant traits in Cape Town, South Africa. *Envir Science & Policy, 85*, 182–192.

Grove, M., Ogden, L., Pickett, S., et al. (2018). The Legacy effect: Understanding how segregation and environmental injustice unfold over time in Baltimore. *Annals of the American Association of Geographers, 108*, 524–537.

Hall, D. M., Camilo, G. R., Tonietto, R. K., et al. (2017). The city as a refuge for insect pollinators. *Conservation Biology, 31*, 24–29.

Hope, D., Gries, C., Zhu, W., et al. (2003). Socioeconomics drive urban plant diversity. *PNAS, 100*, 8788–8792.

Hülsmann, M., von Wehrden, H., Klein, A.-M., & Leonhardt, S. D. (2015). Plant diversity and composition compensate for negative effects of urbanization on foraging bumble bees. *Apidologie, 46*, 760–770.

Hunter, M. C. R., & Brown, D. G. (2012). Spatial contagion: Gardening along the street in residential neighborhoods. *Landscape and Urban Planning, 105*, 407–416.

Kendal, D., Williams, N. S. G., & Williams, K. J. H. (2012). Drivers of diversity and tree cover in gardens, parks and streetscapes in an Australian city. *Urban Forestry & Urban Greening, 11*, 257–265.

Kendal, D., Williams, K. J. H., & Williams, N. S. G. (2012). Plant traits link people's plant preferences to the composition of their gardens. *Landscape and Urban Planning, 105*, 34–42.

Lang, U. (2014). The common life of yards. *Urban Geography, 35*, 852–869.

Larson, K. L., Hoffman, J., & Ripplinger, J. (2017). Legacy effects and landscape choices in a desert city. *Landscape and Urban Planning, 165*, 22–29.

Legendre, P., & Legendre, L. (2012). *Numerical ecology*. Amsterdam: Elsevier.

Leong, M., Dunn, R. R., & Trautwein, M. D. (2018). Biodiversity and socioeconomics in the city: A review of the luxury effect. *Biology Letters, 14*, 20180082.

Lerman, S. B., Narango, D. L., Avolio, M. L., Bratt, A. R., Engebretson, J. M., Groffman, P. M., et al. (2021). Residential yard management and landscape cover affect urban bird community diversity across the continental USA. *Ecological Applications, 31*, e02455.

Lin, B., Meyers, J., & Barnett, G. (2015). Understanding the potential loss and inequities of green space distribution with urban densification. *Urban Forestry & Urban Greening, 14*, 952–958.

Locke, D. H., Ossola, A., Minor, E., & Lin, B. B. (2021). Spatial contagion structures urban vegetation from parcel to landscape. *People and Nature*, pan3.10254.

Lowenstein, D. M., Matteson, K. C., Xiao, I., et al. (2014). Humans, bees, and pollination services in the city: The case of Chicago, IL (USA). *Biodiversity and Conservation, 23*, 2857–2874.

Lowenstein, D. M., & Minor, E. S. (2016). Diversity in flowering plants and their characteristics: Integrating humans as a driver of urban floral resources. *Urban Ecosystem, 19*, 1735–1748.

Luck, G. W., Smallbone, L. T., & O'Brien, R. (2009). Socio-economics and vegetation change in urban ecosystems: Patterns in space and time. *Ecosystems, 12*, 604–620.

Mach, B. M., & Potter, D. A. (2018). Quantifying bee assemblages and attractiveness of flowering woody landscape plants for urban pollinator conservation (I Puebla, Ed). *PLoS One1, 13*, e0208428.

Majewska, A. A., & Altizer, S. (2020). Planting gardens to support insect pollinators. *Cons Biology, 34*, 15–25.

Martini, N. F., Nelson, K. C., & Dahmus, M. E. (2014). Exploring homeowner diffusion of yard care knowledge as one step toward improving urban ecosystems. *Environmental Management, 54*, 1223–1236.

Martins, K. T., Gonzalez, A., & Lechowicz, M. J. (2017). Patterns of pollinator turnover and increasing diversity associated with urban habitats. *Urban Ecosystem, 20*, 1359–1371.

McCune, B., & Grace, J. (2002). *Analysis of ecological communities*. Gleneden Beach, Oregon: Mjm Software Design.

Meyer, A. (2015). Does education increase pro-environmental behavior? Evidence from Europe. *Ecological Economics, 116*, 108–121.

Minor, E., Belaire, J. A., Davis, A., et al. (2016). Socioeconomics and neighbor mimicry drive yard and neighborhood vegetation patterns. *Urban Landscape Ecology: Science, Policy and Practice*, 56–74.

Nassauer, J. I., Wang, Z., & Dayrell, E. (2009). What will the neighbors think? Cultural norms and ecological design. *Landscape and Urban Planning, 92*, 282–292.

Oksanen J, Blanchet FG, McGlinn D, et al. 2020. vegan: Community Ecology Package. R package version 2.5-6.

Ossola, A., Locke, D., Lin, B., & Minor, E. (2019). Yards increase forest connectivity in urban landscapes. *Landscape Ecology, 34*, 2935–2948.

Padullés Cubino, J., Cavender-Bares, J., Hobbie, S. E., et al. (2019). Drivers of plant species richness and phylogenetic composition in urban yards at the continental scale. *Landscape Ecology, 34*, 63–77.

R Core Team. (2019). *R: A language and environment for statistical computing*. Vienna, Austria: R. Foundation for Statistical Computing.

Raymond, C. M., Diduck, A. P., Buijs, A., et al. (2019). Exploring the co-benefits (and costs) of home gardening for biodiversity conservation. *Local Environment, 24*, 258–273.

Ricker, J. G., Lubell, J. D., & Brand, M. H. (2019). Comparing insect pollinator visitation for six native shrub species and their cultivars. *horts, 54*, 2086–2090.

Rudd, H., Vala, J., & Schaefer, V. (2002). Importance of backyard habitat in a comprehensive biodiversity conservation strategy: A connectivity analysis of urban green spaces. *Restor Ecology, 10*, 368–375.

Schell, C. J., Dyson, K., Fuentes, T. L., et al. (2020). The ecological and evolutionary consequences of systemic racism in urban environments. *Science, 369*, eaay4497.

Schwarz, N., Moretti, M., Bugalho, M. N., et al. (2017). Understanding biodiversity-ecosystem service relationships in urban areas: A comprehensive literature review. *Ecosystem Services, 27*, 161–171.

Swan, C. M., Brown, B., Borowy, D., et al. (2021). A framework for understanding how biodiversity patterns unfold across multiple spatial scales in urban ecosystems. *Ecosphere, 12*.

Thomson, F. J., Moles, A. T., Auld, T. D., & Kingsford, R. T. (2011). Seed dispersal distance is more strongly correlated with plant height than with seed mass: Dispersal distance and seed mass. *Journal of Ecology, 99*, 1299–1307.

Turner, V. K., & Stiller, M. (2020). How do homeowners associations regulate residential landscapes?: An analysis of rule structure and content in Maricopa County (AZ). *J of the American Planning Association, 86*, 25–38.

Uren, H. V., Dzidic, P. L., & Bishop, B. J. (2015). Exploring social and cultural norms to promote ecologically sensitive residential garden design. *Landscape and Urban Planning, 137*, 76–84.

van Heezik, Y., Freeman, C., Porter, S., & Dickinson, K. J. M. (2013). Garden size, householder knowledge, and socio-economic status influence plant and bird diversity at the scale of individual gardens. *Ecosystems, 16*, 1442–1454.

van Heezik, Y. M., Freeman, C., Porter, S., & Dickinson, K. J. M. (2014). Native and exotic woody vegetation communities in domestic gardens in relation to social and environmental factors. *E&S, 19*, art17.

Visscher, R. S., Nassauer, J. I., Brown, D. G., et al. (2014). Exurban residential household behaviors and values: Influence of parcel size and neighbors on carbon storage potential. *Landscape and Urban Planning, 132*, 37–46.

Vittoz, P., & Engler, R. (2007). Seed dispersal distances: A typology based on dispersal modes and plant traits. *Botanica Helvetica, 117*, 109–124.

Widows, S. A., & Drake, D. (2014). Evaluating the National Wildlife Federation's Certified Wildlife Habitat[TM] program. *Landscape and Urban Planning, 129*, 32–43.

Zmyslony, J., & Gagnon, D. (2000). Path analysis of spatial predictors of front-yard landscape in an anthropogenic environment. *Landscape Ecology, 15*, 357–371.