



# Assessing social and biophysical drivers of spontaneous plant diversity and structure in urban vacant lots

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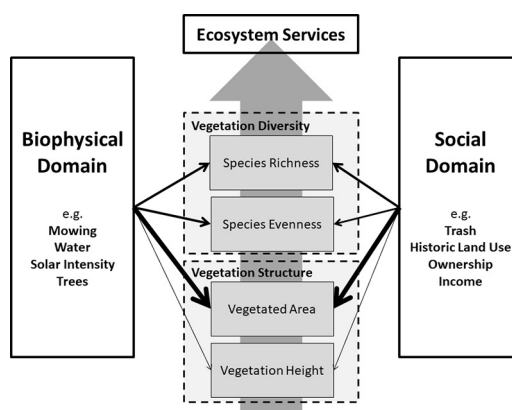
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## HIGHLIGHTS

- Assessed plant richness, evenness, vegetated area, and height in 35 vacant lots.
- Richness and evenness are positively related; species in lots are unlikely to be rare.
- Social and biophysical models both explained vegetation, and sometimes overlapped.
- Trash in a lot was an important explanatory variable for three vegetation measures.

## GRAPHICAL ABSTRACT



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## ABSTRACT

Vacant lots are typically viewed as urban blight but are also green spaces that provide wildlife habitat and ecosystem services in urban landscapes. Vacant lot vegetation results from interacting biophysical and social forces, and studying vacant lot ecology is an opportunity to examine urban socio-environmental intersections. Here, we assess vegetation patterns in vacant lots across Chicago, IL (USA), and ask two questions: 1) How does diversity and structure vary, and 2) how do social and biophysical drivers contribute to this variation? We conducted vegetation surveys in 35 vacant lots in the summer of 2015. In each lot, we identified all herbaceous plants (excluding turf grasses) and woody seedlings and measured species richness, evenness, vegetation height, and total vegetated area. We used field sampled data about human activities and land use in vacant lots (e.g., presence of a path, trash and turf), coupled with sociodemographic data (e.g., income, ethnicity), and fine-scale land cover to construct two models for each vegetation measure: a best-fit biophysical model and a best-fit social model. We then used variation partitioning to compare the relative strength of these models and any overlap between them. In total, we identified 109 plant species. Species evenness was high, suggesting that there are few rare species in this system. Species richness and vegetation height were better explained by social models, while vegetated area and evenness were better explained by biophysical models. We saw evidence of overlapping explanatory power between the social and biophysical domains. The amount of trash in a lot was the most significant variable, explaining three of our vegetation measures. Lots with higher amounts of trash had higher richness and evenness, and lower vegetated area. This assessment of patterns of vegetation in Chicago's vacant lots provides insight into how habitat differs across the city and informs urban conservation paradigms.

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## 1. Introduction

Urban plant communities are key elements of city environments (Boland and Hunhammer, 1999). Plants serve many important social and ecological functions that make cities more livable for both humans and wildlife (Wong and Chen, 2009). Across the heterogeneous urban matrix, plant communities vary with factors such as contemporary and historical land use, ownership, and management (Savard et al., 2000; McKinney, 2006). Plant communities in cities arise in one of three ways; they emerge spontaneously, they are planted, or they are remnants of native vegetation (Rega-Brotsky et al., 2018). Once these novel communities are established, their persistence and dynamics are shaped by intersections of social and biophysical features across space and time (Roman et al., 2018). Socioeconomic factors, such as cultural and ethnic composition and income, influence plant communities (Hope et al., 2008) and may have stronger effects than ecological processes such as dispersal and competition (Alberti et al., 2003). In short, urban plant communities are complex socio-environmental systems and much remains to be learned about their structure, diversity, and drivers.

Vacant lots comprise almost 17% of the land area in US cities (Newman et al., 2016). These spaces are largely vegetated but, unlike other urban lands, the vegetation in vacant lots is rarely planted, watered, or weeded (Kremer et al., 2013). If anything, lots are seeded with turf grass, mowed a few times each year, and the plant community is left to develop on its own (Crowe, 1979). Even though these spaces are maintained through perfunctory care, the origins and management of vegetation in vacant lots is important in determining their ecological and social potential (Rega-Brotsky et al., 2018), which includes resources for wildlife and ecosystem services for human residents (Robinson and Lundholm, 2012). The specific benefits vary with characteristics of the plant community, traits such as plant height and specific leaf area, and the lots themselves (Kim et al., 2016). Deeper knowledge of these lots and the plant communities within them can allow managers and decision-makers to improve urban sustainability (Xiao et al., 2007; Keeley et al., 2013) and wildlife habitat (Sushinsky et al., 2013; Benide et al., 2015).

As with any urban space, there are likely to be trade-offs in terms of the ecological and social functions provided by vacant lots (Kremer et al., 2013; Kim, 2016). For example, lots with taller vegetation provide better habitat for many wildlife species (Ferenc et al., 2014) but might seem unsafe or unsightly to humans. Lots with higher plant diversity and evenness will offer more food and other resources to wildlife (Faeth et al., 2011), but humans may not notice increased diversity (Dallimer et al., 2012) or might consider certain plant and wildlife species as unwanted pests or health risks (e.g., ragweed, Katz et al., 2014). On the other hand, there can be socio-ecological synergies. For example, an increase in vegetated area provides more wildlife habitat while simultaneously reducing urban heat island effects and increasing carbon sequestration (McPherson et al., 2013).

Vacant lots are variable and dynamic (Newman et al., 2016). They differ in their historical land use, their contemporary management, and in their local and neighborhood context (Burkholder, 2012; Nassauer and Raskin, 2014). Some properties have been recently demolished while others were never developed. Some lots are open and sunny while others sit in the shade of tall buildings. Lots vary in terms of foot traffic and other forms of human disturbance. These social and biophysical factors affect the diversity and structure of vegetation in vacant lots (Whitney and Adams, 1980; Hope et al., 2003; Godefroid and Koedam, 2007; Latzel et al., 2008; Grimm et al., 2017), but it is an open question whether social or biophysical factors have a stronger impact and how they interact.

In this paper, we investigate the diversity and structure of vegetation in vacant lots and the relative strength of social and biophysical drivers of these vegetation patterns. We ask two questions: 1) How do plant diversity and structure vary in vacant lots across the city of Chicago, IL

(USA)? and 2) How do social and biophysical drivers contribute to these vegetation patterns? Using a case study of Chicago, Illinois (USA), we aim to provide initial insight into the formation of spontaneous plant communities in urban areas and the resulting habitat they provide.

## 2. Methods

### 2.1. Study sites

This work took place in Chicago, Illinois (USA), the third largest city in the United States. Chicago has a temperate climate, with four distinct and sometimes extreme seasons. Average winter temperatures range between  $-8^{\circ}\text{C}$ – $0^{\circ}\text{C}$  and average summer temperatures range between  $16^{\circ}\text{C}$  and  $28^{\circ}\text{C}$  (U.S. National Weather Service). The city is located on the southwestern shore of Lake Michigan.

At the time of data collection, the city owned 13,703 vacant lots. These lots were in various states of demolition. Some had unsound structures that needed to come down while others had been fully razed. Surprisingly, some had never been built. The vast majority of these vacant lots were clustered in low-income neighborhoods on the south and west side of the city. Information about the location of each lot is available online at the City-Owned Land Inventory ([https://www.cityofchicago.org/city/en/depts/dcd/supp\\_info/city-owned\\_land\\_inventory.html](https://www.cityofchicago.org/city/en/depts/dcd/supp_info/city-owned_land_inventory.html)).

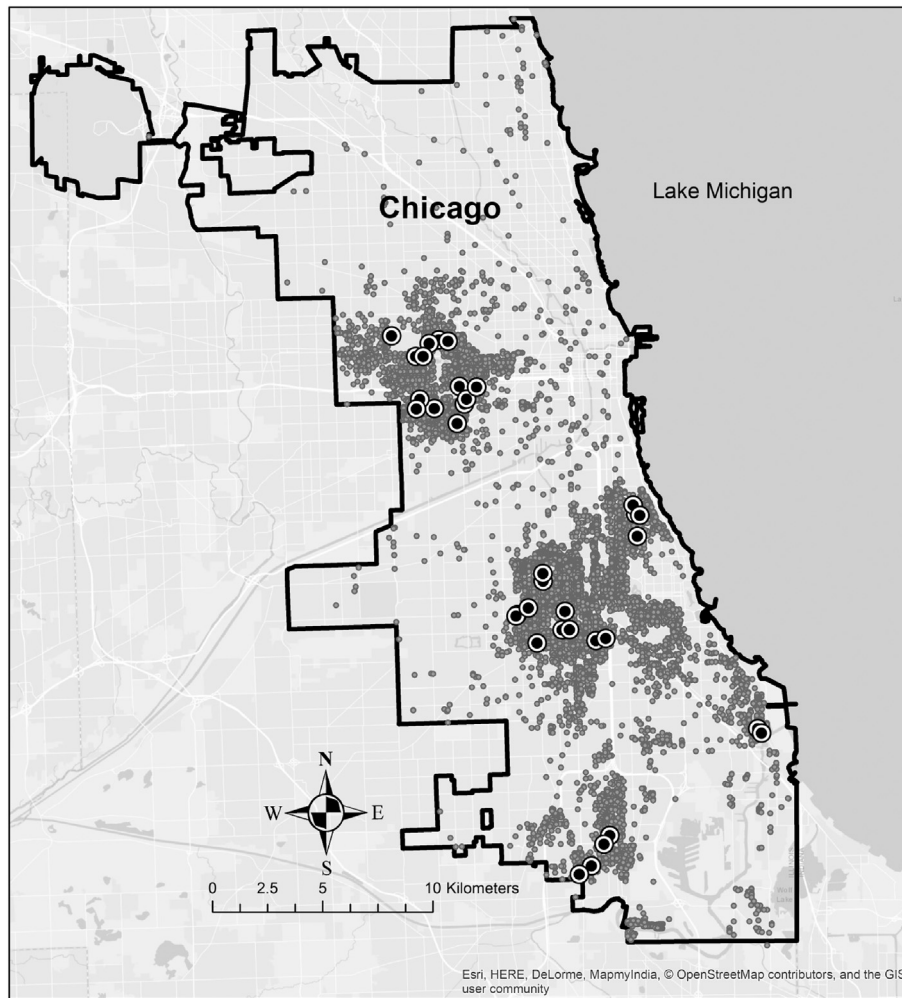
To select field sites, we created a list of 150 randomly selected lots from this inventory. We started at the top of the list and vetted each site using Google Earth Pro™ to ensure vacancy and access. We discarded any sites that appeared to be fully fenced without entry or that had buildings on them. We selected the first 35 sites on the list that were vacant and accessible (Fig. 1). In short, our 35 sites had accessible entry, no buildings, and were randomly selected from the database of city-owned vacant lots.

### 2.2. Field sampling

We visited the 35 vacant lots in summer 2015 to collect information about the plant community and human activity at each site. If the lot was contiguous with other vacant lots, we assessed only the area in the selected parcel. While ecological demarcations are certainly looser than individual parcels, Grove et al. (2015) suggest that urban ecology is most applicable and precise when boundaries are definite and question-specific. For this reason, we defined our individual lots by their tax and property parcel lines. When property lines were not clear, they were determined in situ based on the standard 25 ft. (7.62 m) parcel width in Chicago ([cityofchicago.org/zoning](http://cityofchicago.org/zoning)).

Our primary goal was to assess the herbaceous vegetation (including tree seedlings) at each lot. In order to collect fine-scale data on vegetation and ground cover, we set up a grid of sample points in each lot. The grid covered the entire lot with at least one meter of clearance surrounding any fences or building edges. Sample points in the grid were two meters apart. At each sample point, we identified any plant species (excluding turf grass) and classified vegetation height as short ( $<10$  cm), medium (11–50 cm), or tall ( $>51$  cm). Turf grass—grass species planted as a lawn and usually mowed short—was not included as a species in our community matrix for two reasons. First, it is very difficult to identify to species when the grass has been cut, and most grass seed mixes include multiple species. Second, turf grass has management implications because the grass is maintained to conform to societal norms. Turf grass therefore requires human investment and energy input, regardless of the species present. Individual grasses outside of lawn areas were identified and included in our community dataset.

If no plants were present at a sample point, we recorded the ground cover at that point. Ground cover types included impervious surface, permeable non-vegetated surface (e.g. gravel or woodchips), bare soil, and turf grass. If any sample points were covered by parked cars, we



**Fig. 1.** Map of 35 randomly-selected vacant lots across Chicago where we assessed spontaneous urban vegetation. The city of Chicago is outlined in black, and small grey points are all city-owned vacant lots at our time of sampling. Large black points represent our 35 sampled vacant lots.

marked them as a parking space. At each point, we also noted the presence or absence of trash.

At each vacant lot, we conducted a rapid inventory of human influence by noting presence of unpaved, worn foot paths, fences, parking, and illegal dumping. By our definition, dumping differed from trash in terms of size and ease of disposal; dumping refers to larger items that should have been disposed of in a landfill or via a recycling program (e.g. old tires, mattresses, appliances) while trash refers to smaller items that were likely either discarded by passersby or had blown from nearby trash receptacles.

We also noted whether the lot had been recently mowed at the time of sampling, as evidenced by short vegetation with chopped stalks. We identified and measured the diameter at breast height (DBH) of all trees that extended above the herbaceous vegetation in the interior of the lot and around the perimeter.

### 2.3. GIS data

We used GIS to measure a number of social and biophysical variables at and around each sample location. We obtained categorical information on soil texture in each lot using the US SSURGO Soil Web Survey (USDA Web Soil Survey). The Soil Web Survey classified the soils in our study area as urban (i.e., contains rubble, pollutants, etc.), but also gives an indication as to the primary particle size (clay, sand, silt, or loam). In the absence of field-sampled soil information, this was a suitable metric for incorporating the roles of different soils in plant

communities. We extracted information on solar intensity at the centroid of each of our vacant lots, based on height of surrounding buildings, from the  $10 \times 10$  m data layer used in Lowenstein et al. (2014). We calculated the Euclidean distance from each vacant lot to the nearest nature preserve, which are green spaces that have been preserved or restored with a direct ecological objective; these sites were typically (but not always) located in large city parks (Chicago Data Portal 2012). Finally, we calculated the total contiguous area of vacant parcels if a site was adjacent to other vacant land.

To get a more detailed picture of the surrounding landscape, we used a fine-scale (1 m resolution) land cover dataset classified from 2008 LiDAR and 2010 NAIP satellite imagery (UVM Spatial Analysis Lab). With this dataset, we measured the proportion of canopy cover, grass and herbaceous plant cover, open water, and built area in a 100 m buffer around each vacant lot. These variables directly define the biophysical properties of a given area, which are known to affect plant community assemblages (Godefroid and Koedam, 2007).

To quantify the social landscape surrounding these lots, we extracted data from the 2010 Census for the block-group that contained the vacant lot (US Census Bureau, 2010). We evaluated social characteristics that have been shown to be important in driving plant communities in other urban land use types (Hope et al., 2003; Godefroid and Koedam, 2007). These variables included ethnic composition of neighborhood residents (measured by the proportion of residents of Hispanic descent), median household income, education (proportion of residents with a Bachelor's degree or higher), home ownership (proportion of

residents owning their property), housing density (number of houses per block-group area), the proportion of these houses that were vacant, and housing age (proportion of homes built before 1939). We also calculated the density of businesses in each block group, based on the listing of business licenses on the Chicago Data Portal. To ascertain the historic building footprints, we located our study sites on Sandborn fire insurance maps from 1898 to 1934 (Sanborn Map Company, 1989–1934) and used imageJ (Rasband, 1997–2016, <https://imagej.nih.gov/ij/>) to calculate the proportion of the lot that had been previously built. Lastly, we used the earliest available historic aerial imagery from Google Earth Pro© to assess whether or not there was a building on the property in 1999. This imagery gave a crude indication of how long the lot had been vacant.

#### 2.4. Data analysis

Our goals were to characterize the vegetation in Chicago's vacant lots and ascertain which variables best explain measures of plant community and structure. We were particularly interested in learning whether social or biophysical variables were better predictors of vegetation in these lots. Our approach was to calculate species richness, evenness, and vegetated area, and to classify vegetation height for each lot. We created two models for each vegetation measure: a best-fit biophysical model, and a best-fit social model. We then used variation partitioning to examine the relative importance of, and relationship between, the biophysical and social models.

From the field sampling grid, we calculated species richness and evenness for each vacant lot using the *vegan* package (Oksanen et al., 2016) in R 3.4.1 (R Core Team, 2013). This package calculates Pielou's Evenness by taking the Shannon diversity of an individual site and dividing it by the logarithm of species richness at the site (Oksanen, 2017). We also calculated the portion of each lot that was vegetated (including turf grass), and arcsine squareroot transformed this variable to account for the limits of proportion data. Lastly, we classified the vegetation in each lot as short (>10 cm), medium (11–49 cm), or tall (>50 cm), based on the mode classification for our transect samples. These four vegetation measures served as response variables in separate models, and the predictor variables were biophysical and social variables measured in the field and with GIS (Table 1). We checked all vegetation measures for spatial autocorrelation using a Moran's I global test (R 3.4.1 package *ape*). Since Moran's tests cannot be used for categorical response variables, we assessed spatial autocorrelation between vegetation height and our other vegetation metrics using the arcsine-squareroot transformed proportion of points in a lot classified as tall vegetation.

The first step in our analysis was to assess all explanatory variables to ensure there was no multicollinearity within the social or biophysical sub-groups (Spearman rank correlations <0.60). We eliminated the proportion of residents with a college degree from our variables of interest, as it was highly correlated with median household income (Spearman rank correlation  $\rho = 0.72$ ). We arcsine-squareroot transformed any variables that were based on proportions. We further standardized the biophysical and social matrices of predictor variables using the scale function R 3.4.1. Since we had 12 variables of interests for each of the social and biophysical hypotheses (Table 1), we used a stepwise generalized linear model with backward and forward variable selection (R function *stepAIC* in MASS package, Ripley 2002) to identify the most important variables for species richness, evenness, and vegetated area. We used the same variable selection method for vegetation height, but used an ordinal regression appropriate for our ordered categorical response variable (R function *polr* in MASS package, Ripley 2002). This method of model selection iteratively adds and subtracts individual variables from the full model and converges on the best model based on the lowest Akaike Information Criterion (AIC) value. Due to the large number of variables in each of our models and our overall focus on the interactions between the social and biophysical domains, we did not expect any

interactions between variables to be of interest and therefore excluded them from our assessment.

Our variation partitioning method evaluated the overlap between the final best-fit biophysical and social generalized linear models. For species richness, evenness, and vegetated area, we use the *varpart* function (package *vegan*, R 3.4.1 Oksanen et al., 2016). In this method, each input matrix—made up of the variables indicated by the GLM—is independently assessed as a hypothesis by using linear models to explain variation in the response variable. The variation partitioning method generates an adjusted  $R^2$  value for each individual model that accounts for differences in parsimony. These adjusted  $R^2$  values for the individual models are then examined for overlapping explanatory power by creating a full model with all terms from both models. Therefore, overlaps between models do not represent interaction terms, but rather suggest multicollinearity between hypotheses.

To compare our ordinal regression models for vegetation height, we calculated an adjusted pseudo  $R^2$  value for each of our social and biophysical models independently, and then one for all the variables of both models combined into one. This adjusted pseudo  $R^2$  is calculated by taking the ratio of the log-likelihood for the full model minus  $K$  to the log-likelihood of the null model and subtracting it from 1 (Long, 1997; Hu et al., 2006). We then assessed the differences in adjusted pseudo  $R^2$  manually by subtracting the adjusted pseudo  $R^2$  from the combined model from the sum of the adjusted pseudo  $R^2$  values of our two individual models and dividing by two to identify the magnitude of overlapping explanatory power.

### 3. Results

We identified 109 species of herbaceous and small (<10 cm) woody plants growing in the 35 lots, with a mean richness of 20.6 species per lot. The most common species across all sites were dandelion (*Taraxacum officinale*, 97.1% of sites), white clover (*Trifolium repens*, 94.2% of sites), red clover (*Trifolium pratense*, 91.4% of sites), and black medic (*Medicago lupulina*, 82.8% of sites). Twelve of our 109 species were tree seedlings or small woody shrubs, the most common of which were Siberian elm (*Ulmus pumila*, 45.7% of sites) and white mulberry (*Morus alba*, 17.1% of sites).

On average, vegetated area comprised 76.5% of a given site, but this ranged from 40.4% to 100% across all of our lots. About half of our lots had been recently mowed at the time of sampling (45.7%), but vegetation height was highly variable. Most of our lots (24/35) were classified as medium height (11–49 cm). There were five lots that had no short vegetation, and of these, two were covered completely with vegetation taller than 50 cm. Sixteen sites did not have any trees that extended above the herbaceous vegetation layer. Most of the remaining sites had <1.0 m<sup>2</sup> basal area of trees, with one substantial outlier with 2.3 m<sup>2</sup> basal area. This site contained one exceptionally large cottonwood (*Populus deltoides*) that measured 1.71 m DBH.

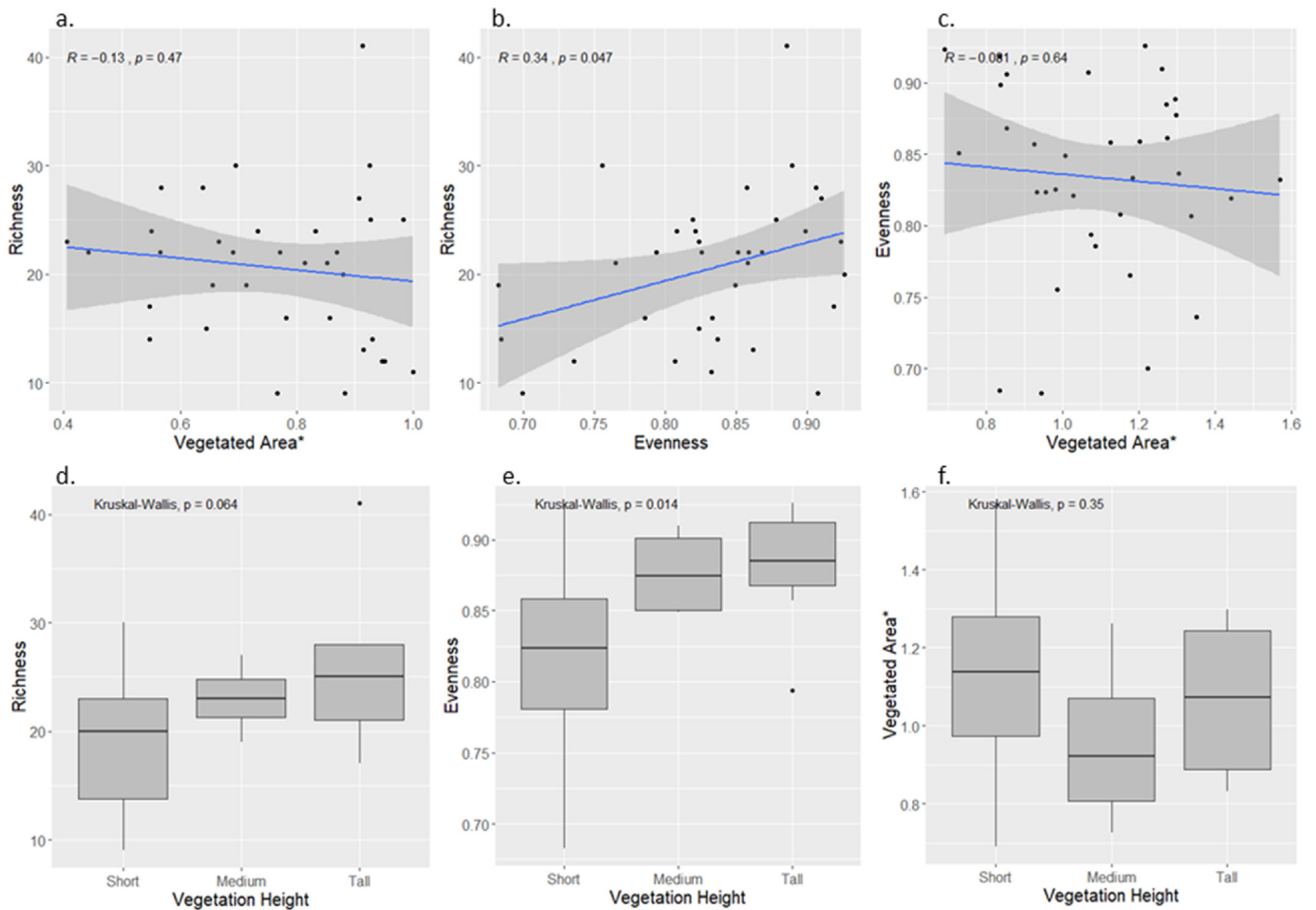
Species richness was positively correlated with species evenness (Pearson Correlation  $\rho = 0.30$ ,  $p = 0.047$ ). Evenness and vegetation height were also related; there was significantly lower evenness in lots with short vegetation (Kruskal-Wallis test,  $p = 0.014$ ). There was a similar, nearly significant pattern for higher richness as vegetation got taller (Kruskal-Wallis test  $p = 0.064$ ) (Fig. 2). No other vegetation measures were highly correlated ( $\rho < 0.30$ , Fig. 2). Furthermore, we did not detect any spatial autocorrelation across the city for any of our vegetation measures (global Moran's I, richness  $p = 0.14$ , evenness  $p = 0.54$ , vegetated area  $p = 0.98$ , proportion of tall vegetation  $p = 0.97$ ).

Our social and biophysical models combined to explain 32% of the variation in species richness at our sites (Fig. 3). The significant variables ( $p < 0.05$ ) in the social model were the amount of trash in a lot and home ownership surrounding the vacant lot (Table 2). The biophysical model (Table 3) contained two significant variables; high richness lots had less turf grass cover and less built area in the surrounding

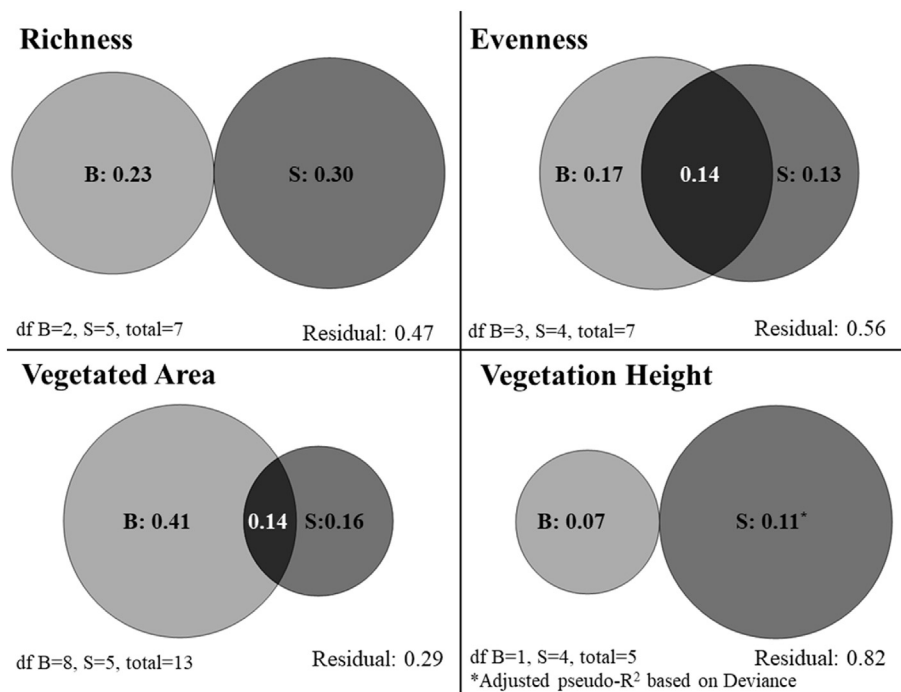


**Table 1**  
Description and sources for all predictor variables used in the model selection for all vegetation measures. Asterisks indicate the variables that were arcsine squareroot transformed before analysis. We cite relevant literature as rationale for many of our variables of interest, particularly in the social realm, to justify our retention of these variables in our full models.

Variable	Description	Mean $\pm$ SE or percent	Source	Rationale
Biophysical				
Bare soil*	Proportion of measured points where bare soil was recorded	0.12 $\pm$ 0.12	Field Sampled	Bare soil has different thermal and hydrological properties and also represents substrate for possible plant colonization. (Schröder et al., 2018)
Mowed	Whether a lot was mowed recently at the time of sampling (Y/N)	Yes: 45.7%	Field Sampled	Recent mowing would cause reduction of biomass and removal of plant material.
Turf grass*	Proportion of the lot covered by turf grass	0.59 $\pm$ 0.03	Field Sampled	Turf grass indicates vegetation management in a lot as it must be planted and maintained.
Basal area	Basal area of trees >10 cm DBH	0.31 $\pm$ 0.07 m <sup>2</sup>	Field Sampled	Basal area of trees indicates shading and potential perches for seed-dispersing birds.
Solar	Solar radiation in a 10 m pixel at the center of the lot, calculated from height of nearby buildings	70,979.15 $\pm$ 151.14	Lowenstein et al., 2014	Solar intensity gives an idea of the amount of sunlight reaching the plants.
Soil texture	Categorical soil texture (clayey, sandy, loamy)	Clayey: 48.6% Sandy: 40.0% Loamy: 11.4%	SSURGO USDA Web soil Survey 2016	Soil texture indicates water drainage and potential for aggregate formation (Schadek et al., 2009).
Grass*	Proportion of a 100 m buffer surrounding the lot comprised of grass/herbaceous cover	0.23 $\pm$ 0.01	2010 CMAP and UVM Spatial Analysis Lab	Surrounding grass/herbaceous cover impacts the hydrology of an area as well as provides a potential seed source.
Canopy cover*	Proportion of a 100 m buffer surrounding the lot comprised of tree cover	0.24 $\pm$ 0.01	2010 CMAP and UVM Spatial Analysis Lab	Trees in the surrounding landscape are important connectors of the urban landscape for seed-dispersing birds (Loss et al., 2009)
Water*	Proportion of a 100 m buffer surrounding the lot covered by water	0.002 $\pm$ 0.003	2010 CMAP and UVM Spatial Analysis Lab	Water in a surrounding buffer gives some insight into hydrology of an area.
Built area*	Proportion of a 100 m buffer surrounding the lot covered by built structures	0.41 $\pm$ 0.03	2010 CMAP and UVM Spatial Analysis Lab	Gives an indication of the thermal and hydrological profile of an area (Godefroid and Koedam, 2007).
Distance to nature space	Euclidian distance to nearest designated nature space	3.69 $\pm$ 0.30 km	Chicago Data Portal	Nature spaces are sources of native seeds and animal dispersers.
Contiguous area	Contiguous area of vacant parcels (only one parcel was measured)	1338.42 $\pm$ 174.89 m <sup>2</sup>	Google Earth Pro©	Larger parcels may support higher species richness and have less edge effects (van Heezik et al., 2013).
Social				
Trash*	Proportion of measured points where trash was recorded	0.09 $\pm$ 0.02	Field Sampled	The amount of trash in a lot may indicate how well-tended a lot is and also may highlight areas where wind drops seeds.
Sides fenced	How many sides of the lot were fenced (0–4)	0: 37.1% 1: 31.4% 2: 14.3% 3: 11.4% 4: 5.8%	Field Sampled	Fencing indicates management and could influence the spread of seeds and bird perching.
Dumping	Whether there were materials that should have been disposed of at a designated facility (e.g. appliances, tires, paint etc. (Y/N)	Yes: 5.7%	Field Sampled	Dumping likely adds pollutants, changes thermal patterns, and is indicative of poor cues to care (Nassauer, 1995, McKinney, 2002)
Foot path	Whether there was a worn footpath through the lot (Y/N)	Yes: 25.7%	Field Sampled	Foot traffic through a lot disturbs and can kill vegetation. Indicative of human use and behavior towards a space (Hobbs and Huenneke, 1992, Zacharias, 2001)
Parking	Whether cars were parked on the lot (Y/N)	Yes: 14.3%	Field Sampled	Results in soil compaction and reduces space for plants to grow. Also indicates human use and behavior towards a space (Hobbs and Huenneke, 1992).
Historic built area*	Proportion of total lot area that comprised a previous building footprint	0.21 $\pm$ 0.04	Sandborn Fire Insurance Maps	Different plants associate with historic yards vs. building footprints in vacant lots (Johnson et al., 2015)
Building 1999	Whether a building existed on the lot in 1999 (Y/N)	Yes: 2.9%	Google Earth Pro©	Gives an indication as to how long the lot has been vacant. Longer vacancies can allow more plant species to establish in a lot (Schadek et al., 2009).
Hispanic population*	Proportion of the Census Block Group community identified as Hispanic	0.05 $\pm$ 0.02	2010 Census Block Group	Different cultural groups are known to have different relationships with land and to cultivate different plant species in their landscapes (Kinzig et al., 2005).
Income	Mean household income in Census Block Group	\$25,657.97 $\pm$ \$1375.14	2010 Census Block Group	Income is known to influence the plant community in areas where homeowners are making land planning decisions (Hope et al., 2008).
Housing density	Housing density per unit area within the Census Block Group	2019.47 $\pm$ 137.26/km <sup>2</sup>	2010 Census Block Group	Housing density in the nearby area gives an indication of population density and intensity of human land use effects.
Owned*	Proportion of homes in the Block Group that are owned (vs. rented)	0.32 $\pm$ 0.03	2010 Census Block Group	Proportion of owned properties gives insight into how invested residents are in their community, which may manifest in different land management.
Built before 1939*	Proportion of houses in the Block Group that were constructed before 1939	0.57 $\pm$ 0.03	2010 Census Block Group	Gives an indication of neighborhood age, which is known to impact diversity (Loss et al., 2009).



**Fig. 2.** Comparisons between our four vegetation metrics with corresponding Pearson correlation coefficients and p values or Kruskal-Wallis p values. Shaded areas in scatter plots correspond with 95% confidence intervals for linear lines of best fit.



**Fig. 3.** Variation partitioning outputs for richness, evenness, vegetated area, and vegetation height models. Circles represent social (S) and biophysical (B) hypotheses, with overlapping segments representing overlapping explanatory power. The numbers in the circles correspond to the total variation (adjusted  $R^2$  for richness, evenness, and vegetated area, pseudo- $R^2$  for vegetation height) explained by each model independently, and the numbers in the overlapped area correspond to the variation that is jointly explained by the two models.

landscape. There was no overlap in explanatory power between the social and biophysical models for species richness.

For species evenness, our biophysical and social models showed slight overlapping explanatory power (14%). Together, these two models explained 44% of the variation in the data, but the biophysical model was slightly stronger, explaining 31% of the overall variation (Fig. 3). The amount of turf grass was the most important biophysical variable and was negatively related to evenness (Table 3). There were three significant variables in the social model: trash, building age, and parking. Having more trash and parked cars in a lot significantly increased evenness, while older buildings in the surrounding landscape was related to lower evenness.

Vegetated area was our best explained vegetation measure; biophysical and social hypotheses had a high level of overlap and together explained 71% of the variation (Fig. 3). By itself, the biophysical model was much stronger than the social model, and also indicated the importance of more variables ( $n = 8$  vs.  $n = 5$ ). The social model indicated significant relationships with the amount of trash, historic built area, and income (Table 2). This was the only vegetation measure that suggested an important effect of soil texture, with both sandy and loamy soils supporting higher vegetated area than clayey soils. In addition to soil texture, we also saw a significant negative effect of the amount of bare soil in a lot. Trees were also important, both in terms of basal area at the lot scale and in the canopy cover of the surrounding landscape. More trees and canopy cover was related to reduced vegetated area.

Our combined social and biophysical models explained 29% of the variation between vegetation height categories. Our best-fit biophysical model had only one variable; intuitively, lots that were recently mowed had shorter vegetation. Dumping was the only significant variable in the social model. Lots with taller vegetation had less dumping than lots with shorter vegetation.

#### 4. Discussion

Vacant lots cover a large area in many cities, and understanding them empirically is critical for urban land reclamation and conservation. Increasingly, these areas are being incorporated into planning for wildlife habitat and green infrastructure (Newman et al., 2016; Minor et al., 2018), both of which depend on the structure and diversity of plants. Our study sought to investigate the diversity and structure of herbaceous vegetation in vacant lots and the drivers of these vegetation patterns. We documented 109 plant species (excluding the grasses in maintained turf) in our sample of 35 lots. We can compare our results to a study by Crowe (1979), who reported 128 species in vacant lots surrounding the University of Chicago. The similarity between our study

and one conducted in the same city over 40 years ago suggests that diversity in vacant lots has been fairly consistent over time.

Species evenness was quite high in our study, suggesting that there are few rare plants in vacant lots. Vegetation cover and height were highly variable, but on average three quarters of a lot was vegetated and vegetation height was under 0.5 m. We found that species richness and vegetation height were better explained by social variables, while evenness and vegetated area were better explained by biophysical variables. Interestingly, in both of the models where social predictors were stronger (richness and vegetation height), there was no overlapping explanatory power between the domains. This suggests a clear separation between the biophysical and social inputs in our system. However, since neither of these combined models explains >53% of the variation in vegetation, these vegetation characteristics certainly merit further investigation. Other unmeasured variables may be driving differences in vegetation. Additional insight could be derived by observing changes in richness over time and more recording more nuanced differences in vegetation height.

Drivers of urban plant diversity and structure are inherently different from those in non-urban areas. This is due in part to the relative strengths of social and biophysical drivers in the two settings (Alberti et al., 2003). In areas less dominated by humans, biophysical factors are the major influences on niche availability and therefore diversity and structure (Carpenter et al., 2009). However, cities are complex, socially-dominated spaces (Grove et al., 2015). In vacant lots, which are relatively neglected lands, we corroborate Johnson et al. (2015) in finding that plant diversity and structure are impacted by contemporary and historic human activities. Surprisingly, the strongest social variable in our study was the amount of trash in a lot, which correlated with increased richness, and evenness, and decreased vegetated area (Fig. 4). While we did not directly assess this relationship, trash may have overlapping social and biophysical implications. From a biophysical perspective, richer lots, which tend to also have taller vegetation, may have a higher propensity for accumulating wind-blown trash. Alternatively, it could be that lots collect wind-blown trash in a way that parallels dispersal of wind-dispersed seeds. Lots with higher trash may receive more wind-borne seeds, thus resulting in higher richness. Socially, however, the amount of trash may serve as a proxy for human investment in a lot. Having more trash may indicate low investment and potentially lower overall satisfaction and management in a given area (Herting and Guest, 1985). This breakdown of management in vacant lots may manifest itself in less vegetated area, but may also allow richer, more even plant communities to establish. To our knowledge, trash has not been explored as a socio-ecological issue in terrestrial systems, but our findings suggest that this could be a critical variable for linking management, cues to care, and ecosystem services in cities. Furthermore, the socio-environmental factors that dictate how much trash is found in a

**Table 2**  
Final social models and standardized effect sizes for all response variables, identified by stepwise model selection from a full model. Direction of the effect is indicated by the sign (+ or -) of the value and shaded cells indicate significant variables at  $\alpha = 0.05$ . Species richness was modeled using a GLM with a Poisson link; evenness, and vegetated area were modeled using a GLM with a Gaussian link. Vegetated area was modeled using an ordinal regression. Asterisks delineate variables that were arcsine-squareroot transformed prior to analysis.

Metric	Trash*	Owned*	Historic built area*	Footpath	Built before 1939*	Parking	Income	Building 1999	Dumping	Hispanic population	Sides fenced
Richness	0.78 ± 0.22	0.51 ± 0.20									
Evenness	0.03 ± 0.01				-0.02 ± 0.01	0.02 ± 0.01					0.02 ± 0.01
Vegetated area*	-0.10 ± 0.03		-0.07 ± 0.03	0.05 ± 0.03	-0.05 ± 0.03		-0.07 ± 0.03				
Vegetation height			2.01 ± 1.22					-3.49 ± 0.13	-0.80 ± 0.40	2.75 ± 1.92	

**Table 3**

Final biophysical models and standardized effect sizes for all response variables, identified by stepwise model selection from a full model. Direction of the effect is indicated by the sign (+ or –) of the value and shaded cells indicate significant variables at  $\alpha = 0.05$ . Species richness was modeled using a GLM with a Poisson link; evenness, and vegetated area were modeled using a GLM with a Gaussian link. Vegetated area was modeled using an ordinal regression. Asterisks delineate variables that were arcsine-square-root transformed prior to analysis.

Metric	Turf*	Mowed	Water*	Built area*	Canopy cover*	Solar	Contig. area	Bare soil*	Basal area	Soil Texture
Richness	–0.09 ± 0.04	–0.08 ± 0.04	–0.09 ± 0.04	–0.09 ± 0.04			–0.06 ± 0.04			
Evenness	–0.04 ± 0.01				–0.01 ± 0.01		–0.02 ± 0.01			
Vegetated area*		0.05 ± 0.02	0.05 ± 0.03	–0.05 ± 0.03	–0.06 ± 0.03	–0.14 ± 0.04		–0.06 ± 0.02	–0.11 ± 0.03	0.06 ± 0.02
Vegetation height		–0.89 ± 0.44								

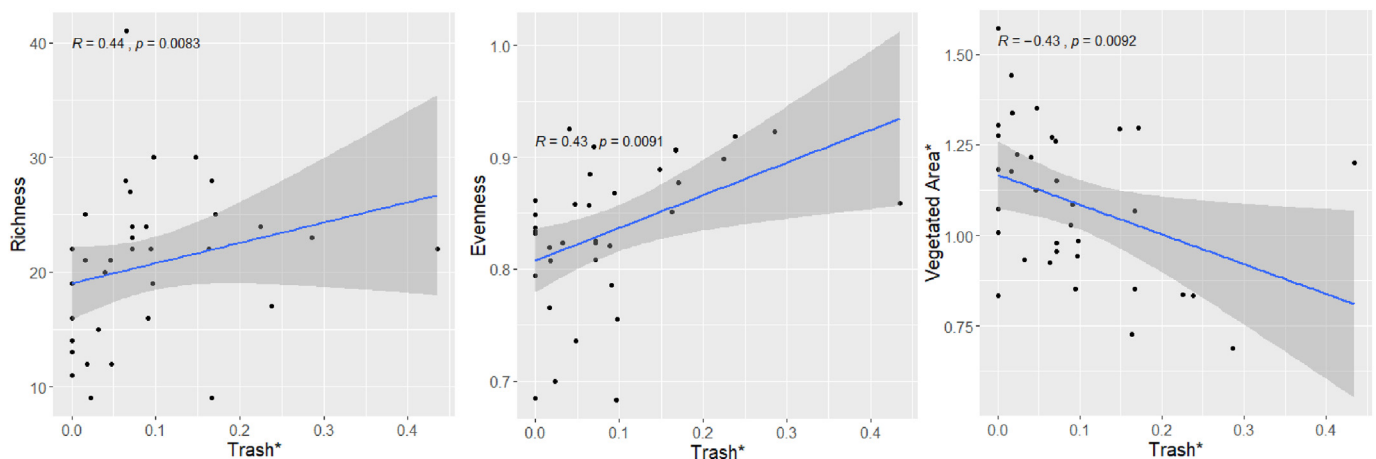
lot are likely complex, but it may be a valuable indicator of the plant community in the absence of more thorough metrics.

We observed a positive relationship between species richness and evenness at the lot level. This provides an interesting comparison between our system and other areas where this relationship has been documented, and was found despite the fact that there was little overlap in explanatory variables for richness and evenness. Zhang et al. (2012) suggest that this relationship is usually negative at small scales (e.g.,  $0.5 \times 0.5$  m), due to small-scale disturbances, but the relationship typically disappears at larger scales. On the other hand, models show that the relationship between richness and evenness should always be positive (Stirling and Wisley, 2001). A positive relationship in our system means that as a new species is added to a lot, it is unlikely to be rare. This suggests that spontaneous urban plants have effective dispersal and colonization mechanisms that allow them to reproduce readily. Our findings corroborate those of Johnson et al. (2018) who suggested that dispersal mechanism is one of the most important factors dictating establishment in vacant lots. Other traits such as small seeds, high fecundity, and the ability to germinate in poor-quality soils have all been linked to urban plant success (Williams et al., 2005; Angold et al., 2006; Thompson and McCarthy, 2008).

The amount of area that is covered by well-maintained turf grass may play a role in linking richness and evenness. Turf grass is managed by regular mowing and is used as a tool to keep weeds at bay (Kamal-Uddin et al., 2009). In our study, we examine mowing as a physical process that results in chopped stems and reduced biomass. However,

mowing is a complex socio-ecological management strategy in cities that is relatively understudied. The constant resetting of successional patterns by mowing arrests vacant lots in a predictable community of ruderal species with low richness and low evenness (Odum, 1971); in short, a near-monoculture of desired turf species. However, even the most aggressive turf maintenance is not perfect, and diverse weeds pop up even under intensive management (Kamal-Uddin et al., 2009). Lots with high turf cover still have sporadic weeds. If mowing is postponed or suspended, vegetation grows taller and these sporadic weeds readily set and disperse seed. Given the ruderal nature of these plants, they produce abundant seeds that germinate easily when they fall on suitable substrate, thus quickly increasing evenness.

Our study reiterates the importance of examining vacant lots from both biophysical and social perspectives (Kim, 2016; Anderson and Minor, 2017). In this regard, the amount of trash in a lot may be a unique variable that can help predict plant diversity, structure, and associated ecosystem services. However, our study is limited to one sampling period in one city. We also did not sample shrubs or census trees <10 cm dbh, which reduces our ability to draw conclusions about habitat, especially for birds. Expansion of this question to other cities with high vacancy may yield distinct patterns. Furthermore, the explanatory power of our models was moderate, and it is likely that more complex spatial and temporal factors are also acting in this system. The seed bank in vacant lots is likely highly dependent on previous land usage and ownership, and differs based on how vegetation was established (Johnson et al., 2018). Spatial patterns throughout the city may offer further



**Fig. 4.** Significant relationships between our three continuous vegetation measure and the proportion of field-sampled points that contained trash. Congruent to our models, vegetated area and the proportion of trash are arcsine square root transformed to meet assumptions of normality and to adjust for limits of proportion. Transformed variables are noted with asterisks. Correlation coefficients and reported p values are based on Spearman Rank Correlations.



insight into how plants grow in vacant lots. Lake Michigan exerts strong environmental effects across Chicago (Hayhoe et al., 2010), and different neighborhoods have different priorities and resources for managing vacant lots and cleaning up trash. On a similar note, better data of direct human activities in vacant lots could provide better context for social models. Furthermore, plant communities and other ecological processes are not confined to individual tax parcels, so understanding interactions with surrounding land use types may also improve our understanding of these spaces. Future work untangling differences in plant community composition—particularly as it relates to ecological function—could clarify some of the variation in diversity and structure.

Vegetation structure and diversity impact the ecosystem services and wildlife habitat a site provides (Savard et al., 2000; McKinney, 2002; Lehmann et al., 2014). Our study adds to the growing knowledge that vacant lots can—and arguably should—be managed to maximize certain benefits (Rega-Brotsky et al., 2018). For example, areas with high plant species richness provide resources for pollinators (Frankie et al., 2005) and are correlated with high-value ecosystem services such as carbon sequestration and oxygen production (Riley et al., 2017). Our results indicate that some of the less tended spaces in cities—unmowed vacant lots with high trash accumulation—may be well suited to providing these services in low-income neighborhoods. However, storm water and heat management—critical urban environmental challenges—may be better addressed by increasing vegetated area and overall plant biomass (Brabec et al., 2002; Desimini, 2013), even though tall vegetation is generally perceived negatively (Hoffman et al., 2012). This conflict between improving wildlife habitat (e.g. by increasing vegetation height) and decreasing social acceptance of a space is indicative of a tradeoff between provisioning and cultural ecosystem services in a residential neighborhood (Andersson et al., 2014). These tradeoffs make it challenging to maximize the benefits of vacant lots across the landscape (Anderson and Minor, 2017). We did not observe a relationship between vegetated area and species richness, and caution that prioritizing vacant lots with extensive vegetation does not maximize biodiversity. Alternatively, vacant lots that simultaneously maximize both are good targets for studying the capacity of vacant lots to contribute to urban conservation.

Contemporary cities are undertaking conservation projects at unprecedented rates (Hartig and Kahn Jr., 2016; Pickett et al., 2016). In Chicago, these include large-scale restorations and natural areas designations, particularly on publicly-owned land such as city parks. In light of these projects, abundant vacant lots with variable vegetation height and diversity may contribute to conservation of some specialist species (Lancaster and Rees, 1979). While these areas do not replace remnant or restored areas, they may be suitable for stepping-stone habitat for target species of birds and pollinators (Bierwagen, 2007; Rega-Brotsky et al., 2018; Lynch, 2018). However, it is important to keep in mind that vacant lots are typically perceived as urban blight (Hoffman et al., 2012). If we want to use this abundant land resource to improve urban sustainability, we must directly address these perceptions. By better understanding the social and biophysical dimensions of vacant lots and their potential to provide valuable ecosystem services, research-informed land management has the potential for improving environmental conditions and environmental justice in dense urban areas.

## 5. Conclusions

Vacant lots are a potentially abundant land resource for ecosystem services and wildlife habitat. These spaces are highly variable in their diversity and structure, and therefore might be good locations for conservation and urban greening efforts. We found that the social and biophysical contexts of vacant lots shape species richness, species evenness, vegetation height, and vegetated area differently, and that for the most part, these metrics of diversity and structure are shaped by factors that are independent of one another. However, there are some notable

overlaps—particularly in relation to species evenness and vegetated areas—that should be considered in attempts to understand and apply vacant lot ecology.

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