Urban Forestry & Urban Greening 124 (2026) 129594

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Original Article

Canopy inequity persists beyond the urban core, but its underlying drivers vary across a large metropolitan region

Lindsay E. Darling[a,b,*], Dexter H. Locke[c], Christine R. Rollinson[a], Roshanak (Roshi) Nateghi[d], Robert T. Fahey[e], Anita T. Morzillo[e], Brady S. Hardiman[b,f]

[a] *The Center for Tree Science, The Morton Arboretum, 4100 IL Rt 53, Lisle, IL 60532, USA*
[b] *Forestry and Natural Resources, Purdue University, 715 W. State Street, West Lafayette IN, IN 47907, USA*
[c] *USDA Forest Service, Northern Research Station, Baltimore Field Station, Suite 350, 5523 Research Park Drive, Baltimore, MD 21228, USA*
[d] *Earth Commons, Georgetown University, Washington DC, USA*
[e] *Department of Natural Resources and the Environment, University of Connecticut, 1376 Storrs Rd., Unit 4087, Storrs, Mansfield, CT 06279, USA*
[f] *School of Sustainability Engineering and Environmental Engineering, Purdue University, West Lafayette, IN, USA*

ARTICLE INFO

Keywords:
Urban ecology
Environmental equity
Tree canopy
Green infrastructure

ABSTRACT

Trees offset many challenges endemic to developed areas, like the urban heat island effect and stormwater runoff. Research has shown that urban areas are racially segregated, and there are broad inequities in the distribution of trees; minoritized neighborhoods have less tree canopy (“canopy”). Most research focuses within major city boundaries, while the majority of Americans live in the broader metropolitan region in suburban or exurban communities. While suburbs and exurbs are growing faster than cities and becoming more demographically diverse, little is known about metropolitan canopy equity. This research focused on the seven-county Chicago metropolitan region, which spans from highly urban to agricultural lands with economically and racially diverse suburbs in between. We separated the region into urban, old suburban, new suburban, and exurban groups, and found that racial segregation varied across the groups as did the extent to which socioeconomic and ecological characteristics correlated with canopy cover. Canopy inequity was lower in exurban and urban areas and highest in the suburbs. We also found that the distribution of canopy in urban areas was mostly explained by housing density and racial and ethnic makeup, while historic land cover and housing age explained more in suburban and exurban areas. Understanding the factors that drive variation in canopy cover across the wide spectrum of community types commonly found in metropolitan regions may assist in drafting effective strategies to increase canopy equity.

1. Introduction

Trees are critical infrastructure in cities; they reduce the urban heat island effect and stormwater runoff (Livesley et al., 2016; Ziter et al., 2019). People who live near trees tend to have better physical health, and walking in areas with trees reduces stress and improves impulse control (Wolf et al., 2020). The benefits that trees provide are particularly needed in minoritized communities, which are often hotter (Hoffman et al., 2020), more prone to flooding (Faber, 2015), and residents who live in these areas are more likely to have heart disease and report poorer mental health (Swope et al., 2022). In North American cities, wealthier, Whiter communities tend to have more tree canopy cover (“canopy”) than minoritized ones, meaning that the neighborhoods that would benefit most from tree-related ecosystem services have the least access to them (Gerrish and Watkins, 2018; Watkins and Gerrish, 2018). The bulk of the research quantifying canopy inequity and its causes has been conducted in core urban areas (e.g., Hoffman et al., 2020; Locke et al., 2021). However, nearly three-quarters of Americans live in suburban and exurban areas (Grant et al., 2013), and these numbers are expected to increase (White et al., 2009). There is currently a dearth of knowledge about whether canopy inequity exists in suburban and exurban areas of the United States, and the factors that explain the spatial distribution of canopy cover across broader metropolitan regions. The need to expand our knowledge of social-ecological systems beyond the urban core has recently been highlighted by Pickett et al. (2026).

---

* Corresponding author at: The Center for Tree Science, The Morton Arboretum, 4100 IL Rt 53, Lisle, IL 60532, USA.
E-mail address: ldarling@mortonarb.org (L.E. Darling).

https://doi.org/10.1016/j.ufug.2026.129594
Received 16 April 2026; Received in revised form 11 June 2026; Accepted 4 July 2026
Available online 6 July 2026

Canopy cover is a commonly used metric to explore relationships between trees and social equity, the urban heat island effect, air quality, water management, and many other urban phenomena. Canopy can be measured in a variety of ways. This includes ground-based methods like extrapolating plot measures across a broader region (i-Tree, 2020). Satellite remote sensing data also can be used, as demonstrated by the 30-m annual canopy cover layer created by the US Geological Services (Dewitz, 2024). However, the course resolution of this product has been demonstrated to underestimate canopy cover in urban areas, where tree canopy is more dispersed than in forested ecosystems (Browning and Locke, 2020; Smith et al., 2010). High-resolution (usually 1 m or less) land cover products are increasingly used to calculate the extent of canopy cover. These products are generally produced using airplane-based remote sensing incorporating both aerial imagery and Light Detection and Ranging (LiDAR). High resolution aerial imagery allows modelers to detect green vegetation, and LiDAR is used to calculate vegetation height, making it possible to differentiate between trees and other vegetation; combining these data allows for nearly 99% correct identification of tree canopy (O'Neil-Dunne et al., 2013). Early versions of high-resolution tree canopy data layers were laborious, time consuming and, therefore, fairly expensive to produce. However, improvements in the collection of LiDAR data, remote sensing methods, and computing power has made it more cost effective to produce these data, which are becoming available more often and across more metropolitan regions, such as those produced by the Arbor Day Foundation (2024).

The current patterns of urban canopy inequity are rooted in the past, as trees are long-lived, slow-growing organisms, and their distribution is the result of interactions between ecological conditions and sociological choices that were made decades ago (Boone et al., 2010; Darling et al., 2025; Roman et al., 2018). Urban tree canopy cover has been shown to be associated with legacies of pre-urban disturbance regimes (natural and anthropogenic) and with the underlying edaphic and physiographic footprint on which our cities have been built (Roman et al., 2018). Cities in the Northeastern United States are in largely forested biomes, and they tend to have relatively a high amount of tree canopy (Volin et al., 2020). In contrast, much of the American Southwest is either desert or Mediterranean biomes, where tree canopy was historically sparse, and continues to be (Volin et al., 2020). Whereas in the Upper Midwestern United States—where prairied and forested ecosystems intersect, the distribution of tree canopy was historically spotty, and the distribution of tree canopy is currently related to the distribution of forests in the pre-colonial era (Darling et al., 2025; Fahey et al., 2012). Across cities, the current distribution of tree canopy is related to the ecological past.

Variation in canopy cover within cities is also strongly related to human decisions, socio-demographic patterns, and social movements. For example, in the United States, Black Americans fled the racism of the Jim Crow South in the early 1900s in what is known as the Great Migration, but when they arrived in northern cities they were met with discrimination through racial covenants that restricted the neighborhoods in which they could live (Rothstein, 2017). This *de facto* segregation was codified by the Federal Housing Administration and the Homeowner's Loan Corp (HOLC) in a program that is now colloquially known as "redlining". This program largely denied federal home loans to communities of color from 1933 to 1968, and its impacts still exist and are observable in those communities. For example, areas that were redlined currently have higher temperatures and have less tree canopy than other neighborhoods (Hoffman et al., 2020; Locke et al., 2021). Canopy inequities are further maintained by a suite of socio-economic factors (Logan and Molotch, 2007). Wealthier residents can afford to purchase homes in more desirable, tree-filled neighborhoods (Boone et al., 2010; Roman et al., 2018). These communities often have more connections to political decision makers, are more likely to advocate for public investments in their neighborhoods (including parks and street trees), and to argue against the siting of industrial infrastructure and interstates, which are major drivers of the clearing of trees and development of impervious surfaces (Grove et al., 2018; Rothstein, 2017). Wealthier residents also have the discretionary income to purchase trees for their properties (Grove et al., 2014), and may feel pressure to landscape their property in the same fashion as their neighbors (Locke et al., 2018; Minor et al., 2016). Understanding how this segregationist history and contemporary social tendencies have driven canopy inequities may allow cities to plan for a more equitable future (Roman et al., 2018).

While the bulk of research on canopy inequity has focused on urban cores (e.g., Gerrish and Watkins, 2018; Watkins and Gerrish, 2018), such patterns may extend to suburban and exurban communities, as they often have a racial and developmental history that is linked to urban centers. Suburban and exurban communities are and have been economically and socially linked to the urban core. In the Midwestern United States, many suburban communities are nearly as old as urban cores, and from the late 1800s to the mid-1900s they were often racially and economically diverse (Sies, 2001). The wealthier, Whiter suburbs of that era tended to be largely residential, with residents commuting to urban areas for work, whereas racially diverse suburbs tended to be more industrial or agricultural (Sies, 2001). The population and spatial extent of suburbs increased from the 1940s to 1960s, when HOLC loans incentivized White families to purchase new homes in these areas (Rothstein, 2017). The redlining that guided these loans extended beyond city boundaries and included some suburban areas (Nelson and Winling, 2023). The trend of wealthy, White suburbanization continued into the 1980s and 1990s when the Baby Boomer generation raised its children amid a trend of new, large houses and lots (Grant et al., 2013). However, considerable diversity existed in suburbs through this era, as older, racially-diverse suburbs remained around many cities (Hanlon, 2008). Currently, suburban communities typically have lower population density than urban areas, larger homes and lots, and tend to be car-centric (Grant et al., 2013). Racial diversity in suburban areas has increased in recent decades—fueled by Hispanic and Asian immigration (Lichter et al., 2023) as well as by urban out-migration (Behrens and Kühl, 2011; Hess, 2021).

Exurban communities lie at the edges of metropolitan regions and have lower population densities than urban and suburban areas (Theobald, 2005). In the Midwestern United States, they often were historically farming communities that sent their products to urban centers for broad distribution (Cronon, 1991). In the past several decades, these areas have experienced population growth (Lichter et al., 2023). As interstates and public transportation expanded, people began to commute for long distances, lured by the relatively low prices of houses on large plots of land (Clark et al., 2009). From 1980 – 2020, the exurban area and population grew faster than urban and suburban areas (Kotkin, 2022). Again, these communities often started as predominantly White, but have since been diversifying, especially with Latino people (Hess, 2021). The diversification of the suburbs and exurbs is not happening under the same explicit and codified segregation as urban cores, but suburban areas are often still economically inequitable, with Black and Hispanic communities exhibiting higher levels of poverty (Hess, 2021).

This research examined the relationships among canopy distribution and socio-demographics, development, and ecology, across urban, old suburban, new suburban, and exurban parts of the Chicago metropolitan region. We examined relationships among sociodemographic variables and tree canopy cover across four development groups, and further explored what factors were more likely to be related to canopy cover across these same groups. We hypothesized that: 1) segregation and canopy inequity would exist across urban, suburban, and exurban groups, and 2) that different sociological, ecological, and developmental factors would contribute to canopy distribution across the development groups. Our research was focused on the seven-county Chicago region, which spans urban core to agricultural lands that include economically and racially diverse suburbs in between. This metropolitan region is ideal for this research because it is racially diverse; contains urban, suburban, and exurban areas; has previously been found to have inequitable canopy distribution (Fan et al., 2019); and is currently engaging in regional efforts to increase canopy equity (Scott, 2018).

2. Data and methods

2.1. Study area

The seven-county Chicago metropolitan region centers around the City of Chicago (population 2.7 million), the third most populous city in the United States. The region contains 284 municipalities and 8.9 million people (US Census Bureau, 2020). The Chicago region lies at the nexus of the tall grass prairies and the eastern deciduous forests. Before Euro-American colonization, it was the homeland of the Council of the Three Fires, which included the Potawatomi, Ojibwe, and Odawa tribes (Lands, 2023). These tribes actively managed the land and used fire to encourage the growth of species that were important to them (Pyne, 1982). Under their management the region was mostly prairie (Fig. 1). Forested areas were more common in the northern parts of the region and in areas that were protected from fire breaks like rivers (Bowles and McBride, 2002). The distribution of precolonial forests has influenced current conditions, as historically forested areas currently have more tree canopy (Darling et al., 2025; Fahey et al., 2012).

The City of Chicago was founded in 1835 (State of Illinois, 2012). At that time, its boundaries contained just 2600 ha. Over the past 180 years, it expanded and annexed other towns and reached its current size of 60,740 ha in 1956 when it annexed the land that made O’Hare International Airport (Cronon, 1991). Some suburbs were established soon after Chicago, for example, the City of Blue Island in 1843, and the City of Evanston was founded in 1857 (State of Illinois, 2012). These suburbs had their own cultures, residences, businesses, and jobs, but they were inextricably linked to Chicago. They produced goods that were sold in Chicago and, for the wealthiest Chicagoans, served as refuges away from the sewage and disease that was endemic in Chicago in that era (Cronon, 1991). In the early 1900s, many industrial neighborhoods south of Chicago were primarily inhabited by foreign-born populations and communities of color. Over the past century, many industries in these neighborhoods closed, but the suburbs remained connected to Chicago,

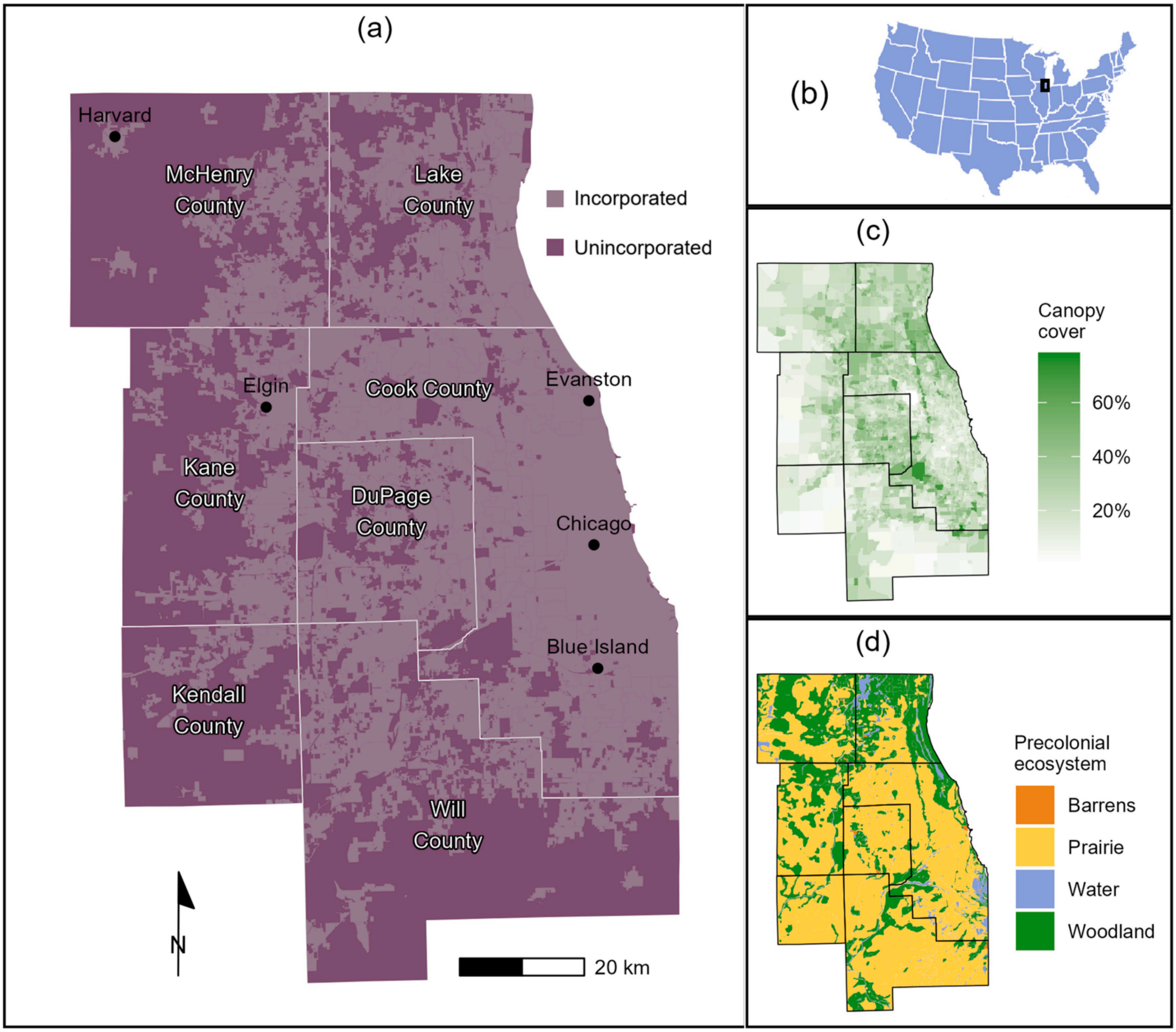


Fig. 1. The seven-county Chicago region, including notable suburban and exurban municipalities (a). The region is located in the Midwestern United States (b). Its tree canopy cover by census block group is shown in (c) and the distribution of precolonial ecosystems in (d).

with residents commuting into the city for work and entertainment. Exurban communities have also long been linked to Chicago. In the 1800s, these communities were largely agricultural, and they used the newly built rail lines to ship their harvests into the Chicago markets where they could be moved across the country (Cronon, 1991), as exemplified by Elgin (established 1854) and Harvard (established 1867) (State of Illinois, 2012). Improvements to interstates and public transportation have allowed residents to live further from Chicago but still regularly commute into the city. This has resulted in an increasing population size of the suburbs and exurbs; a trend which is expected to continue (CMAP, 2024). Both Elgin and Harvard lay at the terminus of commuter rail lines.

2.2. Data preparation

All data preparation and analyses were completed using the R statistical language version 4.2.2 (R Core Team, 2023). Data and code used in this analysis is publicly available (Darling, 2026). Block group-scale census data from the 2017 5-year American Community Survey were accessed using the TidyCensus package (Walker and Herman, 2021). Block groups are the finest scale at which many socio-demographic characteristics are aggregated in the US census. They are drawn to contain 600 – 3000 people; their spatial size is variable. We selected socio-demographic variables that had previously been found to be associated with canopy cover, including: race and ethnicity (specifically, percent of the population that is non-Hispanic White, non-Hispanic Black, and Hispanic) (Watkins and Gerrish, 2018), median household income (Gerrish and Watkins, 2018), housing density (Grove et al., 2014), the average year that houses were built (Grove et al., 2006), and educational attainment (the percent of population with a bachelor's degree or beyond for the population that was aged 25 years or older) (Schwarz et al., 2015). We used US Department of Commerce Census Bureau definitions for race and ethnicity, where race and ethnicity are considered as separate entities. Ethnicity refers to a person's origin, and the US Census only includes Hispanic and non-Hispanic values. The Census includes estimates for many racial values beyond White and Black, including, Asian, American Indian, Pacific Islander, Native American, and others. Nearly half of the Chicago region is not municipally incorporated, and this may explain patterns of land use and canopy distribution (Fig. 1). We calculated the percentage of each block group that was within municipal boundaries to help differentiate between suburban and exurban areas (Nelson, 1992).

The contemporary condition of forests in the Chicago region is related to precolonial ecosystem types, and areas that were forested prior to colonization still have more tree canopy (Fahey et al., 2012). Accordingly, we also calculated the percentage of each block group that was covered by woodlands in the 1830s as identified by McBride and Halsey (2015). They mapped the extent of precolonial ecosystem types (like woodlands, prairies and wetlands) by georeferencing hand-drawn maps from the Pre-Settlement Land Survey. This survey was originally conducted with the stated purpose of allowing colonists to identify plats of land to settle. Finally, we used a 2017 high-resolution land cover layer to quantify the percentage of each block group covered by tree canopy in the contemporary era (Morton Arboretum, 2023). This layer was created by the University of Vermont's Spatial Analysis Lab using an object-based classification of leaf-off LiDAR and leaf-on aerial imagery, both collected in 2017 (O'Neil-Dunne et al., 2013). The layer has a 1-foot resolution, and these methods have been found to be 99% accurate at identifying tree canopy (O'Neil-Dunne et al., 2013). The area of canopy coverage within each block group was calculated using the tabulate area function in ArcGIS Pro (ESRI, 2022), which was then divided by the area of the block group to get percent canopy coverage. All variables and sources are further described in supplemental Table 1.

2.3. Cluster analysis

To analyze trends across the urban to exurban gradient, we assigned each census block group to one of four categories: urban, new suburban, old suburban, and exurban. To do this, block groups within the City of Chicago were first categorized as urban. While some areas in Chicago are less developed, considering the entire city as urban improves the interpretation of the results and recommendations for management, and is consistent with literature (Hess, 2021). Then, the other groups were identified using two iterations of a spatially constrained clustering method leveraged to regionalize geographic areas by building a Minimum Spanning Tree from spatial neighbors and removing edges (to minimize intra-cluster sum of squared deviations) (Hess, 2021). It requires spatially continuous polygons without gaps. This operation was completed using Spatial "K"luster Analysis by Tree Edge Removal (skater) from the package spdep (Bivand et al., 2017). For clustering operations, we used Queen contiguity (where units can be clustered with other units that touch them on sides and vertices) and Euclidean distance. Exurban and suburban areas were differentiated using the attributes of housing density and the percent area of the block group that was municipally incorporated. The cutoffs used to differentiate groups were designated by identifying natural breaks in the data after clustering. While the goal was to differentiate two groups (suburban and exurban), it was necessary to use more groups in the analysis as the groups were not contiguous. We ran the model with ten groups, which was chosen by increasing the number of groups until the output was reasonable and interpretable by regional experts. After clustering, groups were reassigned to the exurban category if the housing density was less than two houses per hectare and suburban if it was greater. Then, new and old suburbs were differentiated from each other by running the same clustering analysis but using the median year that houses were built. The ten clusters were again reassigned into new and old suburbs, with the cut off being the median year that houses were built in the region (1967).

2.4. Statistical analyses

Before any statistical analyses, we filtered the data to remove block groups with no people ($n = 187$), as well as one block group that was an outlier with high population density (5485 people/ha), leaving 5691 block groups in the analysis. We quantified racial segregation across the urbanization categories using Theil's entropy (also known as the H index) in the segregation package (Elbers, 2023). Theil's entropy is a global measure that identifies segregation across multiple groups; in this study we included the number of non-Hispanic Black, non-Hispanic White, and Hispanic residents. H can range from zero to one, with an area that is completely integrated having a zero value and a totally segregated area equaling one. Then, we examined the relationships between tree canopy, income, race, education, and precolonial forests using a correlation matrix. To simplify interpretation, we only used a subset of our socio-demographic variables. Some of these variables had a non-normal distribution, and several of the relationships were not linear. To account for non-normal, non-linear data, we used generalized additive models (GAM) (Wickham, 2016). We tested various numbers and types of splines, and found that using four cubic splines had the lowest AIC.

Socio-demographic and environmental factors in North American cities (and Chicago specifically (Lyall et al., 2025)) are not independent. For example, income, race, and education often covary, which can make simple regressions misleading. Further, these relationships are not necessarily linear. The GAM regressions showed that both collinearity and nonlinearity were present in our dataset. To account for this, we used the random forest machine learning algorithm to explore relationships between socio-demographic variables and canopy abundance with the randomForest package (Liaw and Wiener, 2002). Random forest is an ensemble-of-trees machine learning algorithm and can be used for both regressions and classification (Breiman, 2001; Ho, 1995). Random forest algorithm was ideal for this analysis as it is insensitive to non-normal data distribution, outliers, and collinear variables (Cammarota and Pinto, 2021). Additionally, unlike many other machine learning algorithms, the results generated by a random forest algorithm are interpretable, which allows for the exploration of factors that relate to the distribution of tree canopy (Lyall et al., 2025). We built 500 trees for each random forest model and used six variables at each node. These parameters were selected as the resulting models explained the highest variance. We validated model results by comparing the predicted and actual values and calculating the root mean square error (RMSE) and R^2 of these values. We visualized the importance of variables with Variable Importance Plots (VIP) from the vip package (Greenwell and Boehmke, 2020). VIPs show the relative reduction in model out-of-sample accuracy if a given variable were removed. We scaled all VIPs so that the most highly ranked variable was 100 and the least important variable equaled zero. We also displayed the partial relationships between the four most important variables and canopy cover using Partial Dependence Plots (PDP) from the pdp package (Greenwell and Boehmke, 2020). PDPs for each variable are plotted by keeping all other covariates at their actual observed values, then averaging the model predictions at the fixed values.

3. Results

3.1. Cluster analysis

The cluster analysis showed that the exurban block groups (identified by low population density and areas that were not municipally incorporated) were predominantly located farthest away from the urban City of Chicago (Fig. 2). Cook County, which contains Chicago, had very few exurban block groups, and contained the majority of the old suburban ones. Other, non-contiguous old suburbs were present in Lake, Kane, and Will Counties. New suburbs formed a ring around Chicago, and made up the majority of Lake and DuPage Counties. New suburbs had the highest number of block groups (2323) followed by urban areas (2085) (Table 1). Old suburbs made up the least land area (62,029 ha), followed by urban (62,955 ha). While exurban areas made up the most land area (489,988 ha), they (by definition) had very low housing density (2 houses/ha) and consequently the fewest people overall lived in these areas.

3.2. Socio-demographic makeup

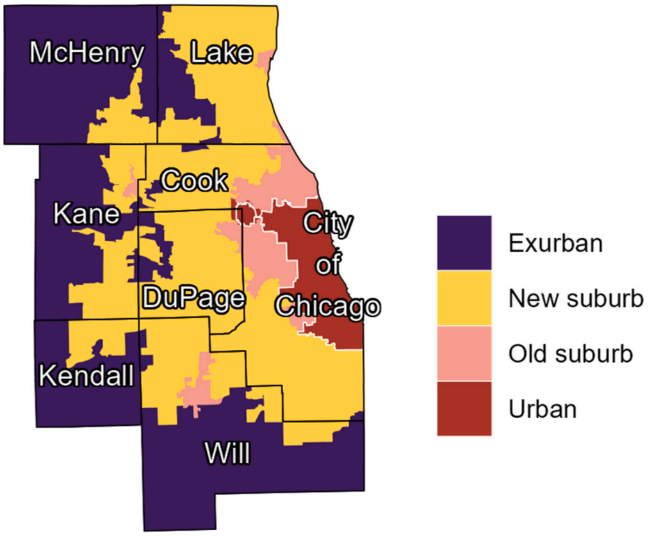


Fig. 2. The seven-county Chicago region divided into four block group types.

Table 1
The mean ± standard deviation of census block-scale data across urban, new suburban, old suburban, and exurban block groups, with large standard deviations suggesting large intra-group variation.

Variables	Overall N = 5691	Exurban N = 291	New suburb N = 2323	Old suburb N = 992	Urban N = 2085
Socio-economic					
Percent non-Hispanic White	50% ± 33%	82% ± 17%	61% ± 28%	53% ± 29%	32% ± 31%
Percent non-Hispanic Black	20% ± 32%	3% ± 8%	13% ± 24%	11% ± 19%	34% ± 40%
Percent Hispanic	22% ± 26%	11% ± 13%	17% ± 20%	28% ± 28%	27% ± 30%
Percent with bachelor's degree	36% ± 24%	32% ± 16%	39% ± 21%	37% ± 26%	34% ± 26%
Median household income	$73 K ± $39 K	$86 K ± $33 K	$83 K ± $38 K	$78 K ± $43 K	$57 K ± $32 K
Percent owner-occupied homes	45% ± 29%	72% ± 18%	57% ± 26%	52% ± 26%	25% ± 23%
Developmental					
Median year housing built	1962 ± 19	1982 ± 15	1975 ± 14	1953 ± 12	1949 ± 14
Households per hectare	20 ± 38	2 ± 2	7 ± 6	13 ± 10	41 ± 56
Environmental					
Percent coverage of precolonial forests	22% ± 35%	45% ± 34%	22% ± 34%	28% ± 40%	15% ± 30%
Percent canopy cover in 2017	26% ± 11%	26% ± 13%	29% ± 11%	28% ± 12%	21% ± 7%

Each variable was significantly different ($p < 0.001$) across the neighborhood types as demonstrated by a one-way ANOVA test.

Socio-demographic, housing, and canopy characteristics varied across the urban to exurban groups, and differences across classes were statistically significant for each variable (Table 1). Urban block groups were the most racially and ethnically diverse, with the population nearly evenly divided among non-Hispanic White, non-Hispanic Black, and Hispanic. Percent non-Hispanic White population increased across old to new suburbs, and was the highest in the exurbs. Exurbs also had the lowest percentages of non-Hispanic Blacks and Hispanics, as well as the lowest poverty rates and percentage of residents with a bachelor's degree, and also had the highest income. Houses were older in urban areas and were progressively newer across old suburbs, new suburbs, and exurban areas. New suburbs had the highest percentage of White residents and percentage of residents with bachelors' degrees. Current canopy cover was the highest in suburban block groups; exurban block groups had substantially more forest cover in the 1830s.

3.3. Segregation

Thiel's H index for the overall Chicago region was 0.47, which is generally considered moderately segregated (Elbers, 2023). Segregation varied across the region, with the urban areas exhibiting the highest segregation ($H = 0.55$), followed by old suburbs ($H = 0.40$) and new suburbs ($H = 0.38$). Exurban areas had the lowest entropy value ($H = 0.21$).

3.4. GAM associations

Socioeconomic variables that are frequently related to canopy inequity in the broader literature (median income, race, and education) (Gerrish and Watkins, 2018; Schwarz et al., 2015; Watkins and Gerrish, 2018), were positively and significantly correlated with canopy cover across the entire Chicago region and across urbanization classes, with the exception of percent non-Hispanic White and median income in exurban block groups (Fig. 3, bottom row). Overall, educational attainment had the strongest correlation with canopy cover. (Pearson's correlation: 0.718, $p < 0.001$). The strength of the relationships between socio-demographic variables and canopy was strongest in the old suburban block groups, followed by new suburbs, and weakest in the exurbs. In urban areas, patterns were significant but much lower Pearson's correlation coefficient values than in suburban areas. The socio-demographic variables were also strongly correlated with each other. In all neighborhood types, census block groups with a higher percentage of non-Hispanic White residents also tended to have higher percentages of residents with a bachelor's degree as well as higher median income. These positive correlations flat-lined above the median income of $125,000 which indicates that the relationship is weaker at the high end, but this may be in part due to very few block groups having a higher income; uncertainty increases sharply above that value.

The density plots (diagonal of Fig. 3) also illustrated differences in the socio-demographics and canopy cover across the neighborhood types. For example, there are a large number of census block groups whose residents are almost all non-Hispanic White in exurban areas, while urban neighborhoods have many block groups with few non-Hispanic White residents. There is considerable variation in percent canopy cover in suburban and exurban block groups, as shown by the broad density curves, but most urban block groups cluster around 20% canopy cover. Fig. 3 only included variables that have been found to consistently correlate with canopy cover for ease of display and interpretation. However, other variables that were used in the random forest analysis also had impacts on canopy cover and covaried with each other. A correlation matrix of all variables is included in Supplemental Figure 1.

The extent of forests in the precolonial era (1830 forest %) was positively correlated with current canopy cover across the region collectively, as well as in each block group type. The relationship was the strongest in exurban areas (Pearson's coefficient = 0.579, $p < 0.001$) and weakest in urban areas (Pearson's coefficient = 0.226, $p < 0.001$). However, relationships between precolonial forests and socio-demographic characteristics were less consistent. In exurban

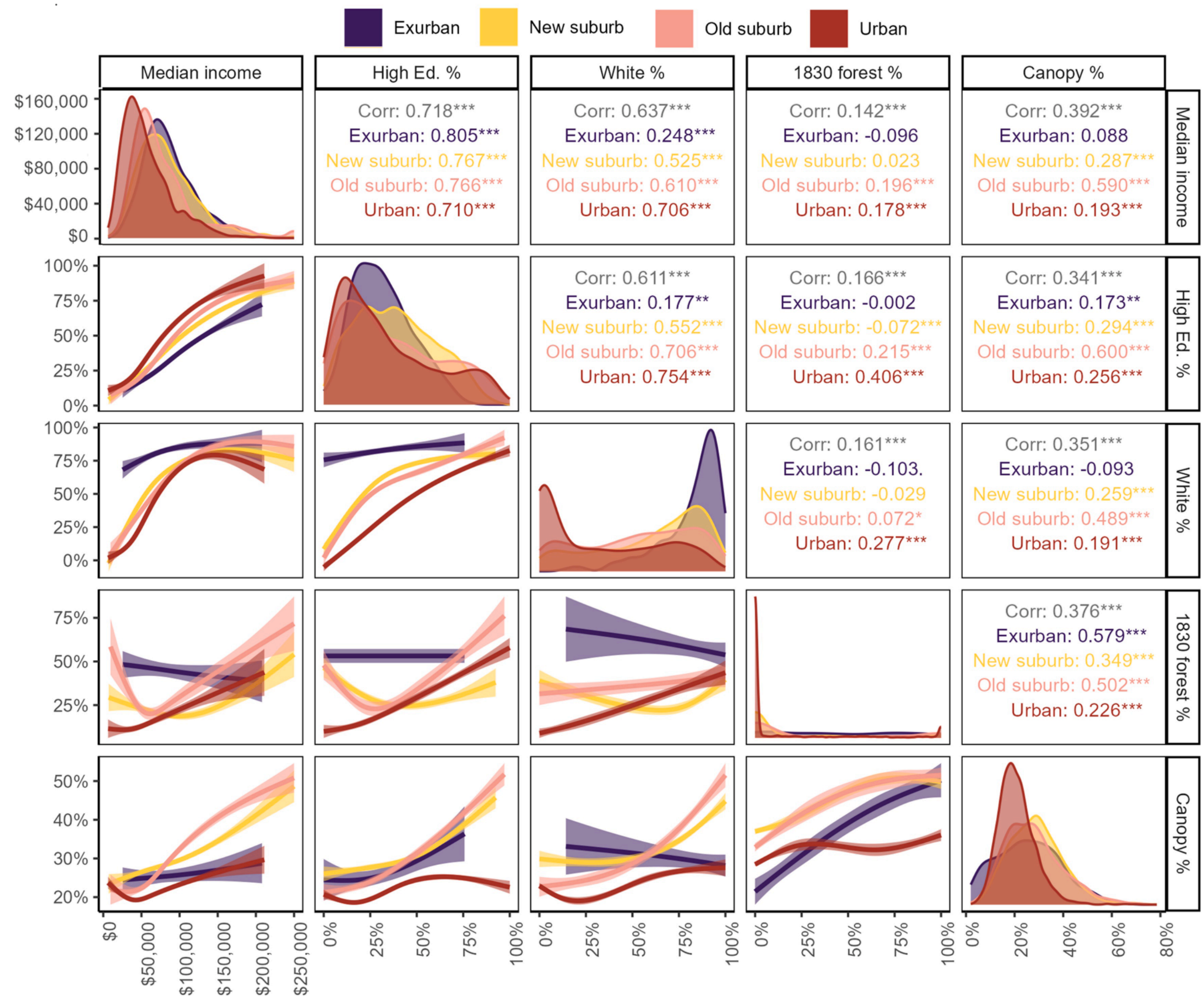


Fig. 3. A correlation matrix of variables associated with canopy equity. Regressions using generalized additive models are on the bottom-left triangle, and they broadly show that socio-demographic variables are correlated with each other in all urbanization classes. Density curves of the samples are on the diagonal and show that the distributions of variables (especially percent White) vary across classes. Pearson correlations and p values are on the top-right triangle and show the magnitude and significance of the correlations. The overall correlation value in gray is for the entire region.

areas, none of the Pearson correlations between precolonial forest and socio-demographics were significant. The opposite trend existed in urban areas where all were positive and significant. In the two suburban block group types, the extent of precolonial forests was non-linear with median income and higher levels of education, with more precolonial cover being associated with both high and low values of these variables.

3.5. Random forest analysis

The random forest model performed best in the old suburban areas, where it explained 64% of variance and the worst in urban areas, where it explained 36% of variance (Fig. 4; see supplemental figure S7 for more information on model fit). The variable importance plots show which

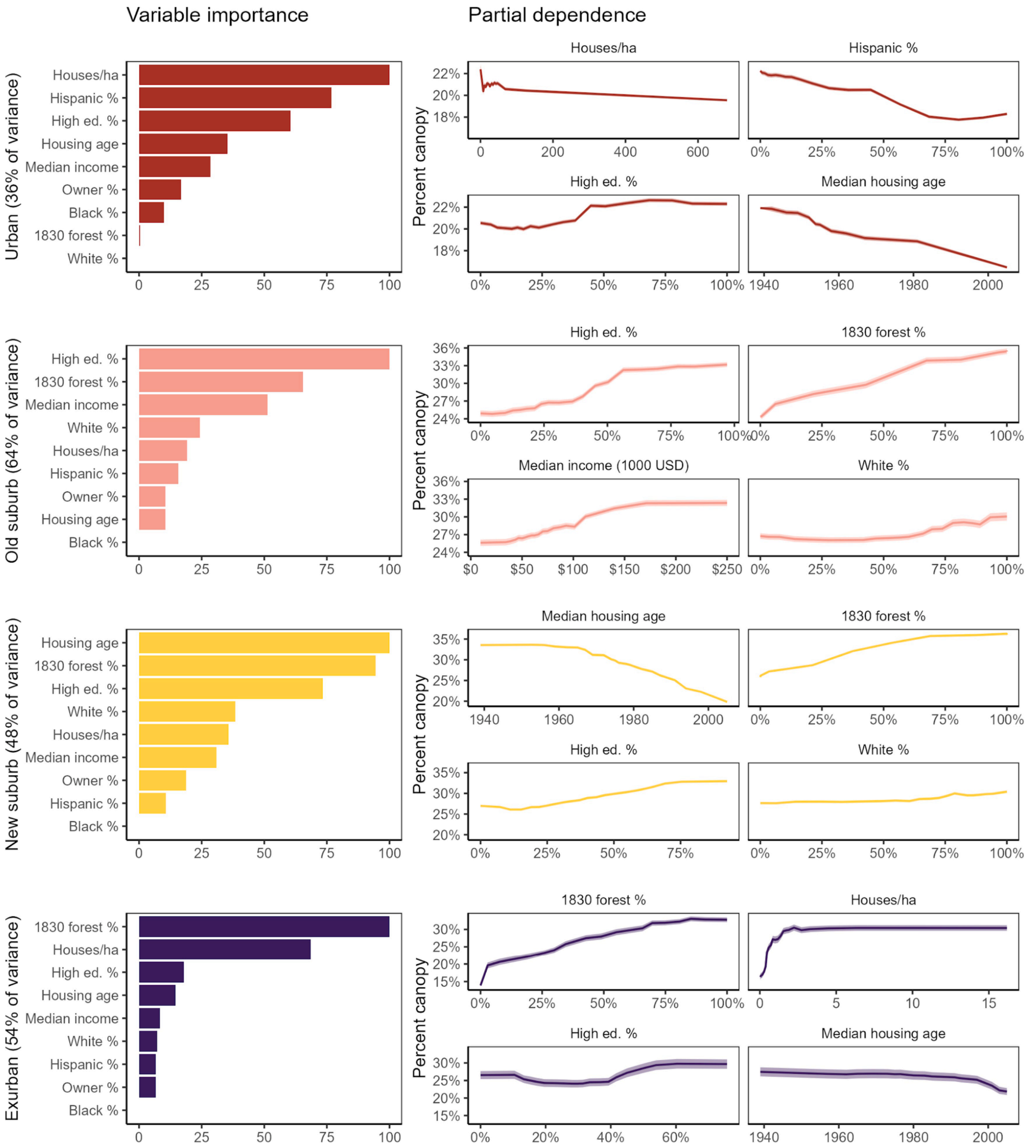
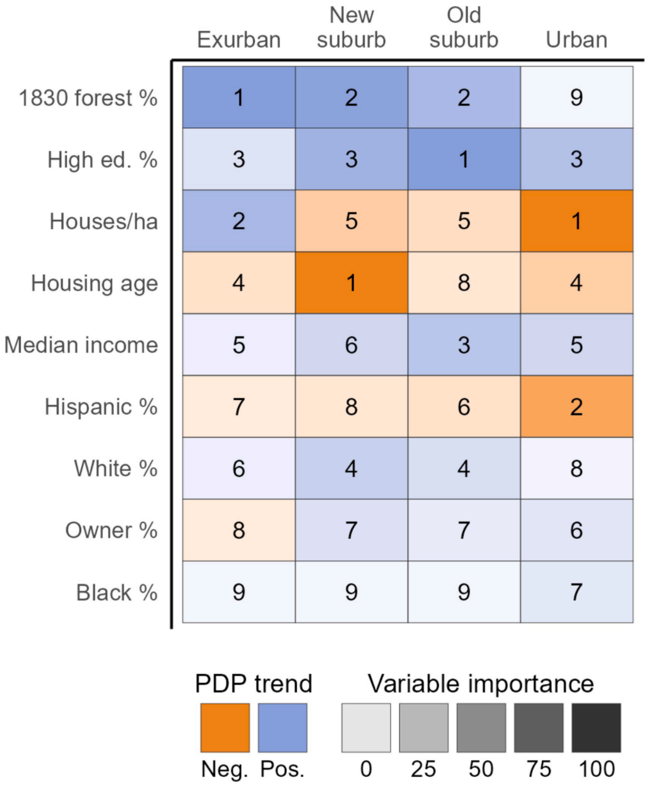


Fig. 4. Variable importance and partial dependence plots for the top 4 variables across urban to exurban block groups. Variable importance shows which variables most strongly influence canopy cover, and was scaled to 100. The most important variable was not the same in any of the urbanization classes. Partial dependence shows how canopy varies with the given variable while controlling for all other variables. For example, canopy cover increased from 26% to 33% in old suburbs while the percentage of the population with a bachelor's degree went from 0% to 100%. Ribbons on partial dependence plots denote 95% confidence intervals (α = 0.05).

variables were most related to canopy distribution, and are scaled with the highest variable equaling 100 and the lowest 0. None of the block group types had the same most important variable, though the extent of precolonial forests was highly ranked in both the suburban and exurban block groups (Figs. 4 and 5). However, this variable was one of the lowest in urban areas where the highest was housing density. Race and ethnicity were not the most predictive variables in any case; Together, they were highest in urban areas, where Hispanic percentage was the second most highly ranked variable. The only variable consistently among the top three most important in all four regions was the percentage of the population with a bachelor's degree or higher (see variable importance and partial dependence plots for the entire region in supplemental figure 6).

Partial dependence plots (PDP) show the relationship between each variable and canopy cover while controlling for the other variables in the model. In urban areas, canopy cover declined steadily as housing density increased. The percentage of a block group that was Hispanic had a strong relationship with canopy cover—there was 4% less canopy cover in areas with the highest percent Hispanic population. The percentage of the population with a Bachelor's degree or beyond was positively associated with canopy cover, but that largely crested at 50% of the population. Median year that houses were built (median housing age) had the largest effect size, with block groups that had houses built after the year 2000 having roughly 4% less canopy than block groups with houses that were built in the 1940s.

In old suburban areas, all of the four most predictive variables (percent of population with a bachelor's degree or beyond, percent precolonial forest, median household income, and percent of the population that is non-Hispanic White) were positively associated with canopy cover. The percent coverage of precolonial forests had the largest effect size; block groups that did not have precolonial forests had 24% canopy cover and those that did had 33% cover.



	Exurban	New suburb	Old suburb	Urban
1830 forest %	1	2	2	9
High ed. %	3	3	1	3
Houses/ha	2	5	5	1
Housing age	4	1	8	4
Median income	5	6	3	5
Hispanic %	7	8	6	2
White %	6	4	4	8
Owner %	8	7	7	6
Black %	9	9	9	7

Fig. 5. Summary of random forest results. The colors represent the overall pattern of the partial dependence plots (PDP), with orange signifying negative association and blue positive. The shading shows the variable importance, with darker shading equaling higher variable importance. The patterns were usually consistent across urbanization classes (with housing density being a notable exception). Numbers in the boxes are the rank from the variable importance plots for each model. All variables were sorted by the average importance across all regions.

Canopy cover in new suburban areas was most strongly related to the year that houses were built (newer housing had less tree canopy) followed closely by the extent of precolonial forests, which had a positive association. The strengths of both of those relationships was relatively strong; areas with the newest housing had around 20% canopy cover but areas with the oldest housing had 34% while the extremes of precolonial canopy extent showed current canopy differences of around 10%. Both the percentage of White residents and areas with more residents had bachelor's degrees were also positively associated with canopy extent, but the relationships were not as strong.

In exurban areas, the extent of precolonial forests had a large impact on the extent of current canopy; block groups without forest were modeled to have half the canopy cover as those that were completely forested. Areas with low housing density had less tree canopy, but once there were more than two houses per hectare that relationship plateaued, likely because there were very few block groups with higher housing density as that variable was used to identify exurban areas. Block groups where greater than 40% of the population had a bachelor degree or beyond had slightly more canopy cover, and the relationship between housing age and canopy was the same as in new suburban block groups but not as pronounced.

Most of the variables had consistent patterns across the block group types (Fig. 5). One notable exception was housing density. While that relationship was negative in urban and suburban areas, it was positive in exurban areas where it was also one of the most important variables. Note that many of these relationships were non-linear and do not have consistent positive or negative associations across their entire spectrum, and that these assignments are a simplification of the overall relationship (to compare all PDPs, see supplemental figures 2 – 5). The percentage of the population that was non-Hispanic White also did not have consistent trends; the correlation was positive in suburban and urban block groups, but negative in exurban (although it was third least important variable in the exurban block groups). The percent of the population that was non-Hispanic Black was consistently one of the least important variables, and it had a positive association with canopy cover across the region.

4. Discussion

Canopy equity varied across the Chicago region, as did the importance of the variables that were predictive of canopy distribution. Understanding the variables that are associated with canopy inequity may help provide guidance for strategies to reduce disparities in mental health, asthma rates, and exposure to extreme heat that are endemic to cities across the United States (Swope et al. 2022). In our study, some measures were consistently important, such as the extent of 1830s forest, which was on average the most important predictor of current canopy extent across the region. In suburban and exurban block groups, the extent of precolonial forests had a stronger association with current canopy cover, but that relationship was weaker in urban areas (Fig. 4 and Supplemental Figure 1). Only 15% of the Chicago region's urban core was covered in precolonial forests (Table 1); the city was mostly prairies and wetlands (Fig. 1) (Bowles and McBride, 2002). Over two centuries of intense development, more forested area was lost in urban block groups (Fahey and Casali, 2017). This has resulted in precolonial conditions having little impact on current canopy in urban areas. There were more precolonial forests in suburban and exurban block groups, and the distribution of that canopy may have influenced development and current tree canopy patterns.

Our results also suggested that suburban block groups were racially segregated and that the relationships between canopy and measures of socio-economic status were strong, which could indicate that wealthier residents were more able and willing to purchase homes in areas that were already forested, as described by Boone et al. (2010) and Roman et al. (2018). Further, these areas often have larger lots, which can allow for the planting of new trees and the retention of existing ones. These patterns were consistent with what has been broadly observed in urban areas (Gerrish and Watkins, 2018; Watkins and Gerrish, 2018), but to the authors' knowledge have not been documented in suburban areas nor across a broad metropolitan region. Much of the overall canopy in these wealthier, Whiter areas is often still in forested natural areas (Darling et al., 2025). Afforestation projects in under-resourced communities may create more ecological parity; however, it is important for planners to ensure that these forests are well stewarded and achieve the goals of the people who live in these neighborhoods (Riedman et al., 2022). Planting along streets and in parks may be an effective strategy; targeted tree planting projects at the site and municipal scale can help achieve health and climate goals and increase social cohesion (Pataki et al., 2021).

A non-significant relationship between canopy and socio-economic variables could occur in two situations: 1. if socio-economic groups were homogeneously distributed (i.e., not segregated) variations in canopy cover were not related to socio-economics, or 2. if an area was segregated but canopy is distributed without relation to that segregation or is evenly distributed. While the urban block groups were the most segregated in the region, the magnitude of the relationships between canopy and socio-economic status was less pronounced (though still significant and positive) than the two suburban classes (Fig. 2). However, in exurban areas, only the relationship between education and canopy was significant; Pearson's correlation coefficient values were lower for all other relationships. We suspect that this may be related to exurban areas being not as racially diverse (Table 1), subsequently they were not segregated, and therefore exhibited weaker correlations between canopy and socio-economic variables. Both new and old suburban block groups were relatively segregated and exhibited strong relationships between variables associated with higher socio-economic conditions and canopy. Given the high level of segregation and strong correlations between canopy cover and socio-economic variables, it is important to consider interventions in suburban areas to address tree inequity. Further research on other metropolitan regions could determine if the patterns that were observed in the Chicago region exist more broadly. If this is the case, it may indicate that national-scale interventions may be helpful in achieving canopy equity in the suburban communities where the plurality of Americans live.

The less pronounced relationship between canopy inequity in urban areas was surprising, as many manuscripts have defined this relationship across North America and beyond (e.g., Gerrish and Watkins, 2018; Watkins and Gerrish, 2018). To the authors' knowledge there are no studies that quantify canopy inequity strictly inside of Chicago's boundaries as this study did, but several documented it in Cook County (Fan et al., 2019; Lyall et al., 2025). The random forest model did not perform as well in the urban, Chicago areas—it only explained 36% of variation. Together, these findings suggested that Chicago proper may contrast patterns of canopy inequity, and that the factors that influence canopy distribution are not restricted to socio-economic or ecological conditions alone.

Across the Chicago region, areas with newer housing had less canopy cover; the median year that housing was built was one of the strongest predictors of canopy cover and was negatively related. While development in areas that are naturally forested nearly always comes at the cost of removing trees (Morgenroth et al., 2017), much of the new development in the region (especially in exurban and new suburban areas) is occurring in areas that were previously agricultural fields–and prairie before that. Recent development in these areas has trended towards lower-budget, starter homes (Grant et al., 2013), and rate of development in these areas is likely to increase in the coming decades (CMAP, 2024; White et al., 2009). If municipalities and counties draft ordinances that encourage tree plantings and ongoing tree maintenance within these new developments, it could facilitate lower-income areas developing equitable tree canopy, especially if suburban and exurban areas become more diverse. In urban and old suburban areas, development is more likely to lead to the removal of existing trees (Morgenroth et al., 2017). Tree ordinances that mandate the protection of trees, levy fees for their removal, and require replanting are possible mechanisms to help preserve existing trees and encourage regrowth when trees are lost (Pike et al., 2021). Maintaining current tree canopy is one of the most effective ways to grow overall canopy cover (Lyall et al., 2025). This involves the protection and maintenance of existing trees, while adding new trees and caring for them as they become established (Vogt et al., 2015).

Across urban and suburban areas, canopy cover was negatively associated with housing density. This is expected, as housing and other development reduces the amount of space where trees can be planted. However, this relationship was the opposite in exurban areas, and it was one of the most predictive variables. In Chicago region exurban areas, block groups with very low housing density are likely agricultural fields. While a few trees may be planted around homesteads and between fields, these places are largely devoid of tree canopy. In areas with more housing, more trees are planted, although this relationship largely levels out at three houses per hectare. Again, if these agricultural areas are developed into housing, it may be important to ensure that tree plantings align with development to protect canopy equity in exurban areas.

In the Chicago region, targeted efforts to expand canopy in Hispanic communities would have the biggest impact on increasing tree equity as percent Hispanic was the most important race and ethnicity variable and was consistently negatively correlated with canopy. This is especially true in urban areas, where it was the second most important variable for the prediction of canopy cover. Lack of Spanish language outreach has been found to be an important barrier to tree plantings in Hispanic communities (Riedman et al., 2022), consistent with language barriers with other green infrastructure efforts (Everett et al., 2023). Increasing canopy cover in Hispanic communities will likely depend on Spanish language outreach as well as working with neighborhood organizations in those communities to ensure that trees are wanted and taken care of. We suspect that the association between Hispanic communities and low canopy is not unique to the Chicago region, and highlights the importance for other metropolitan regions to identify where canopy inequities exist and what communities they impact. Doing this will enable effective outreach tailored to the needs and priorities of diverse communities.

Addressing inequity outside of urban cores may be particularly challenging because these areas are often managed by multiple, and at times overlapping, entities. In the Chicago region, there are 294 municipalities, with 135 in Cook County alone. Additionally, nearly half of the region is unincorporated, and these areas may be managed by counties, townships, non-governmental organizations, individuals, or some combination thereof. Similar patterns of forest management across government and non-governmental organizations exist in metropolitan regions across the United States (Morzillo et al., 2022). There are often socio-economic disparities among municipalities, which may have contributed to persistent disinvestment in municipalities that lack a tax base to fund forestry operations. Within cities, redistribution of funds and resources between affluent and under-resourced areas would increase equity. However, distributing funding to smaller, under-resourced entities may depend on involvement of governmental or organizational levels beyond individual municipalities. Examples of this include the longstanding urban and community forestry funding that is allocated by the United States Department of Agriculture's Forest Service and distributed by individual state's Departments of Natural Resources or their equivalents (USDA Forest Service, 2026).

There are limitations to this study that can inform future research. The correlation-based methods employed did identify varying patterns of inequity across the Chicago region, but cannot identify what caused these patterns. Also, the pre-colonial data were originally recorded at half-mile intervals and then interpolated using GIS. These methods are accurate at a landscape scale, but less so at fine scales (Manies and Mladenoff, 2000), and could introduce some errors when calculating the percentage of each block group that was forested in the 1830s. Census block groups are the finest scale that these socio-demographic data are available. However, there can be considerable variation within block groups. Block groups are drawn to contain similar numbers of people, and they can be relatively large in areas with low population density. We calculated tree canopy cover across the entire block group, which could mask finer scale variation in the demographics-canopy cover relationships. Further, public and private tree canopy can provide different types and levels of ecosystem services (Kardan et al., 2015), and this study did not consider ownership. Finally, this work focused on a single metropolitan region. While patterns of tree canopy inequity have been consistently demonstrated in urban areas (Gerrish and Watkins, 2018; Watkins and Gerrish, 2018), it is unclear if the patterns observed in Chicago's suburban and exurban areas would be consistent elsewhere.

Sustained efforts to plant and care for trees beyond the urban core–including across municipal boundaries, within under-resourced communities may help improve canopy equity in the places where the majority of Americans live. The ecological and sociological variables that were associated with canopy cover varied across the Chicago region, and would likewise differ across other metropolitan regions. The region-wide high-resolution imagery that was used in this analysis is becoming increasingly available across the United States (Claggett et al., 2025; Freese, 2024). Replicating this sort of analysis in other regions may identify consistent trends or variation in how canopy distribution changes across metropolitan regions. This, along with expanding other ecological studies beyond the urban core could extend our understanding of, and thereby our ability to address green equity.

CRediT authorship contribution statement

Robert T. Fahey: Writing – review & editing, Conceptualization. **Anita T. Morzillo:** Writing – review & editing. **Christine R. Rollinson:** Writing – review & editing. **Roshanak (Roshi) Nateghi:** Writing – review & editing, Methodology, Formal analysis. **Brady S. Hardiman:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Lindsay E. Darling:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Dexter H. Locke:** Writing – review & editing, Investigation, Formal analysis.

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.

Acknowledgements

We would like to thank members of the Forest and Urban Systems Ecology Lab at Purdue University for their support, insights, and suggestions throughout the development of this manuscript. Kanaan Hardaway (Purdue University) and Miranda Mockrin (US Forest Service) provided constructive feedback on a prior version of this paper. Funding was provided by USDA awards 2023–6801238992 and 2024–67021–42879. The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or U.S. Government determination or policy.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2026.129594.

References

Arbor Day Foundation, 2024. Trees at Work [WWW Document]. Trees Work. URL ⟨https://hub.treesatwork.org⟩ (accessed 5.29.26).

Behrens, J., Kühl, K., 2011. The changing face of migration: opportunities for urban planners in the American suburb. Berkeley Plan. J. 24, 131–138. https://doi.org/10.5070/bp324111869.

Bivand, R., Altman, M., Anselin, L., Assunção, R., Berke, O., Bernat, A., Blanchet, G., 2017. Package 'spdep.'. Spat. Depend. Weight. Schemes Stat. R. Package Version 1, 1.

Boone, C.G., Cadenasso, M.L., Grove, J.M., Schwarz, K., Buckley, G.L., 2010. Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. Urban. Ecosyst. 13, 255–271.

Bowles, M., McBride, J., 2002. Pre-European Settlement Vegetation of Cook County. Illinois. Rep. Cook Cty. For. Preserve Dist. Corlands Nat. Conserv. Morton Arbor. Lisle Ill.

Breiman, L., 2001. Random Forests. Mach. Learn. 45, 5–32.

Browning, M.H., Locke, D.H., 2020. The greenspace-academic performance link varies by remote sensing measure and urbanicity around Maryland public schools. Landsc. Urban. Plan. 195, 103706.

Cammarota, C., Pinto, A., 2021. Variable selection and importance in presence of high collinearity: an application to the prediction of lean body mass from multi-frequency bioelectrical impedance. J. Appl. Stat. 48, 1644–1658.

Claggett, P., McDonald, S., O'Neil-Dunne, J., MacFaden, S., Walker, K., Guinn, S., Ahmed, L., Buford, E., Kurtz, E., McCabe, P., Pickford, J., Royar, A., Schulze, K., 2025. Chesapeake Bay Land Use/Land Cover (LULC) Database 2024 Edition. https://doi.org/10.5066/P14BEBRC.

Clark, J.K., McChesney, R., Munroe, D.K., Irwin, E.G., 2009. Spatial characteristics of exurban settlement pattern in the United States. Landsc. Urban. Plan. 90, 178–188.

CMAP, 2024. CMAP Growth Areas [WWW Document]. URL ⟨https://cmap.illinois.gov/regional-plan/goals/recommendation/integrate-land-preservation-into-strategic-growth-efforts/⟩ (accessed 11.15.24).

Cronon, W., 1991. Nature's Metropolis: Chicago and the Great West. Norton and Company, New York, New York, USA.

Darling, L.E. Data and code for manuscript Canopy inequity persists beyond the urban core, but its underlying drivers vary across a large metropolitan region. https://doi.org/10.5281/zenodo.21206561.

Darling, L.E., Rollinson, C.R., Fahey, R.T., Morzillo, A.T., Johnson, L.R., Baker, M., Aronson, M.F., Hardiman, B.S., 2025. Ecological and developmental history impacts the equitable distribution of services. Front. Ecol. Environ. 23, e2841.

Dewitz, J., 2024. Natl. Land. Cover. Database (NLCD) Tree Canopy Cover. Prod. https://doi.org/10.5066/P9JZ7AO3.

Elbers, B., 2023. A method for studying differences in segregation across time and space. Sociol. Methods Res. 52, 5–42.

ESRI, 2022. ArcGIS Pro V, 2.

Everett, G., Matsler, A.M., Chan, F.K.S., Naclerio, M.A., Morzillo, A.T., Lamond, J.E., 2023. Lifestyle and language barriers influence community engagement with green infrastructure. Ambio 52, 1650–1660.

Faber, J.W., 2015. Superstorm Sandy and the demographics of flood risk in New York City. Hum. Ecol. 43, 363–378.

Fahey, R.T., Bowles, M.L., McBride, J.L., 2012. Origins of the Chicago urban forest: composition and structure in relation to pre-settlement vegetation and modern land-use. Arboric. Urban. For. 38, 181–193. https://doi.org/10.48044/jauf.2012.027.

Fahey, R.T., Casali, M., 2017. Distribution of forest ecosystems over two centuries in a highly urbanized landscape. Landsc. Urban. Plan. 164, 13–24. https://doi.org/10.1016/j.landurbplan.2017.03.008.

Fan, C., Johnston, M., Darling, L., Scott, L., Haifeng, F., Liao, F.H., 2019. Land use and socio-economic determinants of urban forest structure and diversity. Landsc. Urban. Plan. 181, 10–21. https://doi.org/10.1016/j.landurbplan.2018.09.012.

Freese, D., 2024. Census Tract. Land. Cover. Tree Canopy Anal.

Gerrish, E., Watkins, S.L., 2018. The relationship between urban forests and income: A meta-analysis. Landsc. Urban. Plan. 170, 293–308. https://doi.org/10.1016/j.landurbplan.2017.09.005.

Grant, J.L., Nelson, A.C., Forsyth, A., Thompson-Fawcett's, M., Blais, P., Filion, P., 2013. The future of the suburbs. Suburbs in transition/The resettlement of America's suburbs/Suburbs in global context: the challenges of continued growth and retrofitting/Suburban urbanity: Re-envisioning indigenous settlement practices/Toward a new suburban A. Plan. Theory Pract. 14, 391–415. https://doi.org/10.1080/14649357.2013.808833.

Greenwell, B.M., Boehmke, B.C., 2020. Variable Importance Plots—An Introduction to the vip Package. R. J. 12, 343–366.

Grove, J.M., Locke, D.H., O'Neil-Dunne, J.P.M., 2014. An Ecology of Prestige in New York City: Examining the Relationships Among Population Density, Socio-economic Status, Group Identity, and Residential Canopy Cover. Environ. Manag. 54, 402–419. https://doi.org/10.1007/s00267-014-0310-2.

Grove, M., Ogden, L., Pickett, S., Boone, C., Buckley, G., Locke, D.H., Lord, C., Hall, B., 2018. The legacy effect: understanding how segregation and environmental injustice unfold over time in Baltimore. Ann. Assoc. Am. Geogr. 108, 524–537.

Grove, J.M., Troy, A.R., O'Neil-Dunne, J.P.M., Burch, W.R., Cadenasso, M.L., Pickett, S. T.A., 2006. Characterization of households and its implications for the vegetation of urban ecosystems. Ecosystems 9, 578–597. https://doi.org/10.1007/s10021-006-0116-z.

Hanlon, B., 2008. The decline of older, inner suburbs in Metropolitan America. Hous. Policy Debate 19, 423–456. https://doi.org/10.1080/10511482.2008.9521642.

Hess, C., 2021. Residential Segregation by Race and Ethnicity and the Changing Geography of Neighborhood Poverty. Spatial Demography. Springer International Publishing. https://doi.org/10.1007/s40980-020-00066-3.

Ho, T.K., 1995. Random decision forests. in: Proceedings of 3rd International Conference on Document Analysis and Recognition. IEEE, pp. 278–282.

Hoffman, J.S., Shandas, V., Pendleton, N., 2020. The effects of historical housing policies on resident exposure to intra-urban heat: A study of 108 US urban areas. Climate 8. https://doi.org/10.3390/cli8010012.

i-Tree, 2020. i-Tree Eco Manual [WWW Document].

Kardan, O., Gozdyra, P., Misic, B., Moola, F., Palmer, L.J., Paus, T., Berman, M.G., 2015. Neighborhood greenspace and health in a large urban center. Sci. Rep. 5, 11610. https://doi.org/10.1038/srep11610.

Kotkin, J., 2022. Exurbia Rising. Am. Aff. J. 1.

Land, N., 2023. Native Land Digital [WWW Document]. URL ⟨https://native-land.ca/⟩ (accessed 7.28.23).

Liaw, A., Wiener, M., 2002. Classification and regression by randomForest. R. N. 2, 18–22.

Lichter, D.T., Thiede, B.C., Brooks, M.M., 2023. Racial diversity and segregation: Comparing principal cities, inner-ring suburbs, outlying suburbs, and the suburban fringe. RSF Russell Sage Found. J. Soc. Sci. 9, 26–51.

Livesley, S.J., McPherson, G.M., Calfapietra, C., McPherson, E.G., Calfapietra, C., 2016. The Urban Forest and Ecosystem Services: Impacts on Urban Water, Heat, and Pollution Cycles at the Tree, Street, and City Scale. J. Environ. Qual. 45, 119–124. https://doi.org/10.2134/jeq2015.11.0567.

Locke, D.H., Hall, B., Grove, M., Pickett, S.T.A., Ogden, L.A., Aoki, C., Boone, C.G., O'Neil-Dunne, J., 2021. Residential housing segregation and urban tree canopy in 37 US Cities. Npj Urban. Sustain. 1. https://doi.org/10.1038/s42949-021-00022-0.

Locke, D.H., Roy Chowdhury, R., Grove, J.M., Martin, D.G., Goldman, E., Rogan, J., Groffman, P., 2018. Social norms, yard care, and the difference between front and back yard management: examining the landscape mullets concept on urban residential lands. Soc. Nat. Resour. 31, 1169–1188. https://doi.org/10.1080/08941920.2018.1481549.

Logan, J.R., Molotch, H.L., 2007. Urban fortunes: The political economy of place. Univ of California Press.

Lyall, J., Darling, L., Locke, D.H., Hardiman, B.S., 2025. Turning a New Leaf: Social and Land Use Drivers of Urban Tree Canopy Change in the Chicago Metropolitan Area 2010-2017. Urban. For. Urban. Green., 128999

Manies, K.L., Mladenoff, D.J., 2000. Testing methods to produce landscape-scale presettlement vegetation maps from the US public land survey records. Landsc. Ecol. 15, 741–754.

Mcbride, J., Halsey, S., 2015. Vegetation of the Prairie Peninsula Region of Southern Lake Michigan as Mapped by the Public Land Survey 1829-1835. The Morton Arboretum and the US Geological Service, Lisle, IL.

Minor, E., Belaire, J.A., Davis, A., Franco, M., 2016. Socioeconomics and neighbor mimicry drive yard and neighborhood vegetation patterns. in: Urban Landscape Ecology. Routledge, pp. 74–92.

Morgenroth, J., O'Neil-Dunne, J., Apiolaza, L.A., 2017. Redevelopment and the urban forest: A study of tree removal and retention during demolition activities. Appl. Geogr. 82, 1–10.

Morzillo, A.T., Campbell, L.K., King, K.L., Lautar, K.J., Scott, L., Johnson, M.L., Clarke, M., Rhodes, L., Pincetl, S., Sonti, N.F., others, 2022. A tale of urban forest patch governance in four eastern US cities. Urban. For. Urban. Green. 75, 127693.

Nelson, A.C., 1992. Characterizing exurbia. J. Plan. Lit. 6, 350–368.

Nelson, R., Winling, L., 2023. Mapping Inequality: Redlining in the New Deal America. Digit. Scholarsh. Lab.

O'Neil-Dunne, J.P.M., MacFaden, S.W., Royar, A.R., Pelletier, K.C., 2013. An object-based system for LiDAR data fusion and feature extraction. Geocarto Int. 28, 227–242.

Pataki, D.E., Alberti, M., Cadenasso, M.L., Felson, A.J., McDonnell, M.J., Pincetl, S., Pouyat, R.V., Setälä, H., Whitlow, T.H., 2021. The benefits and limits of urban tree planting for environmental and human health. Front. Ecol. Evol. 9, 603757.

Pickett, S.T.A., Zhou, W., Childers, D.L., Grove, J.M., Hansen, W.D., Locke, D.H., Boone, C., Seto, K.C., Zhaxi, D., LaDeau, S., Nevarez, L., Freudenberg, R., Solomon, C.T., Cook, E.M., Urban-Mead, R., Maddox, D., Bosch, A.R., 2026. The continuum of urbanity: a synthetic concept for research on urban-rural mixtures. Npj Urban. Sustain. https://doi.org/10.1038/s42949-026-00347-8.

Pike, K., O'Herrin, K., Klimas, C., Vogt, J., 2021. Tree preservation during construction: an evaluation of a comprehensive municipal tree ordinance. Urban. For. Urban. Green. 57, 126914.

Pyne, S.J., 1982. Fire Primeval. Sciences (6), 14–20.

R Core Team, 2023. R: A language and environment for statistical computing.

Riedman, E., Roman, L.A., Pearsall, H., Maslin, M., Ifill, T., Dentice, D., 2022. Why don't people plant trees? Uncovering barriers to participation in urban tree planting initiatives. Urban. For. Urban. Green. 73, 127597.

Roman, L.A., Pearsall, H., Eisenman, T.S., Conway, T.M., Fahey, R.T., Landry, S., Vogt, J., van Doorn, N.S., Grove, J.M., Locke, D.H., Bardekjian, A.C., Battles, J.J., Cadenasso, M.L., van den Bosch, C.C.K., Avolio, M., Berland, A., Jenerette, G.D., Mincey, S.K., Pataki, D.E., Staudhammer, C., 2018. Human and biophysical legacies shape contemporary urban forests: a literature synthesis. Urban. For. Urban. Green. 31, 157–168. https://doi.org/10.1016/j.ufug.2018.03.004.

Rothstein, R., 2017. The color of law: A forgotten history of how our government segregated America. Liveright Publishing.

Schwarz, K., Fragkias, M., Boone, C.G., Zhou, W., McHale, M., Grove, J.M., O'Neil-Dunne, J., McFadden, J.P., Buckley, G.L., Childers, D., Ogden, L., Pincetl, S., Pataki, D., Whitmer, A., Cadenasso, M.L., 2015. Trees grow on money: urban tree canopy cover and environmental justice. PLoS. ONE 10, 1–17. https://doi.org/10.1371/journal.pone.0122051.

Scott, L., 2018. Chicago Region Trees Initiative Master Plan. The Morton, Arboretum, Lisle, IL. https://mortonarb.org/plant-and-protect/chicago-region-trees-initiative/2050-master-plan-for-trees/.

Sies, M.C., 2001. North American suburbs, 1880-1950: cultural and social reconsiderations. J. Urban. Hist. 27, 313–346.

Smith, M.L., Zhou, W., Cadenasso, M., Grove, M., Band, L.E., 2010. Evaluation of the national land cover database for hydrologic applications in urban and suburban Baltimore, Maryland 1. JAWRA J. Am. Water Resour. Assoc. 46, 429–442.

State of Illinois, 2012. Illinois Counties and Incorporated Municipalities (No. 11.23).

Swope, C.B., Hernández, D., Cushing, L.J., 2022. The relationship of historical redlining with present-day neighborhood environmental and health outcomes: a scoping review and conceptual model. J. Urban. Health 99, 959–983.

The Morton Arboretum, 2023. 2017 High-resolution Chicago Region Land Cover. https://doi.org/10.17605/OSF.IO/62NVZ.

Theobald, D.M., 2005. Landscape patterns of exurban growth in the USA from 1980 to 2020. Ecol. Soc. 10. https://doi.org/10.5751/ES-01390-100132.

US Census Bureau, 2020. American Community Survey.

Vogt, J., Hauer, R.J., Fischer, B.C., 2015. The costs of maintaining and not maintaining the urban forest: a review of the urban forestry and arboriculture literature. Arboric. Urban. For. 41, 293–323.

Volin, E., Ellis, A., Hirabayashi, S., Maco, S., Nowak, D.J., Parent, J., Fahey, R.T., 2020. Assessing macro-scale patterns in urban tree canopy and inequality. Urban. For. Urban. Green. 55, 126818. https://doi.org/10.1016/j.ufug.2020.126818.

Walker, K., Herman, M., 2021. Tidycensus: Load US Census Boundary and Attribute Data as "tidyverse" and 'sf'-Ready Data Frames. R package version 0.11.4.

Watkins, S.L., Gerrish, E., 2018. The relationship between urban forests and race: a meta-analysis. J. Environ. Manag. 209, 152–168. https://doi.org/10.1016/j.jenvman.2017.12.021.

White, E.M., Morzillo, A.T., Alig, R.J., 2009. Past and projected rural land conversion in the US at state, regional, and national levels. Landsc. Urban. Plan. 89, 37–48.

Wickham, H., 2016. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.

Wolf, K.L., Lam, S.T., Mckeen, J.K., Richardson, G.R.A., Bosch, M.V.D., Bardekjian, A.C., 2020. Urban Trees and Human Health: A Scoping Review. Int. J. Environ. Res. Public. Health 17.

Ziter, C.D., Pedersen, E.J., Kucharik, C.J., Turner, M.G., 2019. Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. Proc. Natl. Acad. Sci. 116, 7575–7580.