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An overview of urban greening-urban forestry environmental analysis tools in the United States of America

Sean M. Mullen[a], Richard W. Harper[a], David V. Bloniarz[a], J. Rebecca Hargrave[b] and Olga Kostromytska[c]

[a]Department of Environmental Conservation, University of Massachusetts Amherst, Amherst, MA, USA; [b]Department of Environmental Sciences; School of Agriculture, Business & Technology, State University of New York, Morrisville, NY, USA; [c]Stockbridge School of Agriculture, University of Massachusetts Amherst, Amherst, MA, USA

ABSTRACT

Though urban green spaces and urban forests provide essential ecological and human health benefits, their distribution may be uneven, often disadvantaging low-middle income (LMI) and racially diverse communities. This review explores the effectiveness of urban greening environmental justice (EJ) analysis tools in relation to urban forestry applications. Specifically, the methodologies, user interfaces, and practical applications of five prominent EJ mapping tools – Tree Equity Score, EJScreen, CalEnviroScreen, ParkScore, and i-Tree – were evaluated. The unique abilities including customisability and capacity, as well as features and limitations of each tool were considered. Potential enhancements like real-time data integration, and community engagement to increase the tools' utility and impact were discussed, and case studies of real-world application of each of these tools were explored. The powerful abilities of EJ mapping tools in supporting informed policy decisions and promoting environmental justice through equitable urban greening initiatives were outlined. Our conclusions underscore the importance of accessible, user-friendly, and comprehensive EJ tools in advancing environmental equity in the urban forestry sector.

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Introduction

Urban forests are essential components of urban landscapes. Comprised of trees, shrubs, and greenspaces, urban tree plantings provide numerous human health and ecological benefits, such as carbon storage and sequestration, pollution abatement, and stormwater management (Akbari, 2002; Berland et al., 2017). One of the most impactful benefits is the shade offered by the trees that constitute the urban forest, as it has the potential to cool buildings and reduce energy consumption (Akbari et al., 2001; McDonald et al., 2019; Ziter et al., 2019). Additionally, shade provided by city trees has the potential to decrease the urban heat island effect by shielding exposed concrete, thus reducing surface temperatures (Akbari et al., 2001; McDonald et al., 2019; Ziter et al., 2019). The urban forest also improves air quality by sequestering a variety of

CONTACT Richard W. Harper rharper@eco.umass.edu

pollutants, including particulate matter and ozone – an estimated 651,000 tons (590,577.27 tonnes) of pollutants are removed by urban trees in the United States every year (Nowak et al., 2006, 2014). These benefits counteract some facets of environmental degradation that may be exacerbated by urbanisation and climate change.

The distribution of urban greenspaces – including urban forests – is often uneven, with low-income and minority-majority neighbourhoods historically being afforded limited access to these areas (Gerrish & Watkins, 2018; Wolch et al., 2014). Residents in these communities may be more likely to experience health issues from exposure to increased environmental hazards as well as the lack of access to greenspace (Coutts et al., 2010). Understanding how environmental inequality arises is an important step in remedying these injustices (Grove et al., 2014). Several theories outline the emergence of urban vegetation distribution patterns that tend to disadvantage under-represented and low-middle-income (LMI) communities. These theories include population density, social stratification, and reference group behaviour (Grove et al., 2014). Possible explanations examined in these theories include that as families gain wealth they move to areas with greater amenities which often feature plentiful access to greenspaces; that power and income differences between neighbourhoods influence the amount of public investment in local green infrastructure; that certain socio-economic groups are better able to attract public investment in greening initiatives (Grove et al., 2014; Locke & Grove, 2016).

In recent years, the term “Environmental Justice” has become broadly used, particularly in the discipline of urban forestry. This term is defined in several manners, including:

(i) the equitable exposure to environmental good and harm (Wolch et al., 2014).
(ii) the fair treatment and meaningful involvement of all people regardless of race, colour, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies (U.S. Environmental Protection Agency, 2016).
(iii) to the greatest extent practicable and permitted by law, all populations are provided the opportunity to comment before decisions are rendered on proposed Federal actions (U.S. Department of Agriculture, 2012).

While the definition that Wolch et al. (2014) posit outlines disparity in relation to environmental burden, it does not include language regarding how equity might be achieved. However, the definitions provided by both US federal agencies (US Environmental Protection Agency, US Department of Agriculture), describe meaningful engagement with diverse stakeholders from the community – often considered to be a foundational component of both environmental justice and successful urban greening/urban forest management (Carmichael & McDonough, 2018).

Statements by the Biden administration have affirmed an understanding and advancement towards environmental justice in relation to the disbursement of federal funding for initiatives that include urban greening. At an Earth Day ceremony in the recent past, former President Biden declared,

> We've put environmental justice at the center of what we do, addressing the disproportionate health, environmental, and economic impacts that have been borne primarily by communities of colour — places too often left behind.
>
> (April 22, 2022)

This has been written into practice through the "Justice40" initiative that declares,

> … that 40 percent of the overall benefits of certain Federal investments flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution.
>
> (Biden, 2024)

This initiative was enacted with the passing of the Inflation Reduction Act of 2022, where over $1 billion USD was budgeted for urban greening initiatives and programmes in disadvantaged communities. With this well-resourced push to remedy environmental injustices, the importance of identifying an accurate and comprehensive means of describing these injustices in relation to urban greening and urban forestry has emerged. This is where effective use of environmental justice mapping tools has the potential to greatly enhance a community's efforts to secure funding for green infrastructure projects.

Environmental justice mapping tools are used to analyse, describe, and foster understanding related to injustices at the community level. This may include both a thorough evaluation of current environmental and economic hardships – such as the lack of access to green space – and a long-term benefits analysis of new green infrastructure. A wide range of environmental justice mapping tools already exist, each with a different approach on how to communicate environmental justice issues. Some tools are visually oriented with the inclusion of simple coloured maps, while other tools provide a more sophisticated understanding in the form of detailed spreadsheets as they draw from a range of databases to deliver a comprehensive examination of an extensive range of environmental information and long-term benefits analysis of proposed green infrastructure. This review will detail the background and uses of five prominent environmental justice mapping tools and an assessment of their effectiveness as vectors for information about environmental justice within the context of the practice of urban forestry.

Methods

Scholarly databases such as Web of Science and ScienceDirect, as well as websites of relevant U.S. government agencies (e.g. EPA, OEJ, and Justice40) and environmental organisations (e.g. American Forests, Climate Justice Alliance, and The Trust for Public Land) were searched with the intention of identifying publications that detail specific environmental justice mapping tools. Keywords and phrases used included "environmental justice", "urban forestry", "greenspace", "equity", and "analysis", in conjunction with the names of specific mapping tools obtained by interfacing with subject matter experts. The search process also involved exploring reference lists and bibliographies of relevant articles and reports to identify additional sources.

Data collection involved documenting key information from selected publications, including technical reports that describe the creation of the mapping tools, their features, case studies, and any challenges or limitations. To verify the functionality of the identified mapping tools, a practical exploration of these suites was initiated to gain firsthand experience with their user interfaces and capabilities. The selection of the specific mapping tools to assess both arose inductively and was corroborated through consultation with subject matter experts (i.e. expert elicitation) within the urban forestry sector (Elton et al., 2022) to the point where they were narrowed to: "Tree Equity Score," "EJSCREEN," "CalEnviroScreen," "ParkScore," and "i-Tree." The findings were synthesised in a comparative format to highlight the strengths and weaknesses of the different tools.

Results

Tree equity score

Developed in 2021 by American Forests, Tree Equity Score (https://treeequityscore.org) is a tool designed to portray the distribution of urban tree canopy cover across communities in the United States. It provides high-resolution data on tree canopy cover in relation to various socio-economic and environmental factors using a scoring method that allows users to identify areas that lack adequate tree coverage for the purpose of prioritising tree preservation and future planting efforts. Scores are calculated at the census block level by using inequality indicators that incorporate poverty level, heat disparity, and minority population. The measures of inequality are then compared with the specific amount of canopy cover in that area. The scores range from 0 to 100. Areas of high inequality and low canopy cover receive a low equity score, while areas with adequate or better canopy cover will be higher.

The Tree Equity Score's interface is a simple, user-friendly map where municipalities and census block groups are colour-coded based on their score, with higher scores showing as dark green and lower scores ranging from light green to red (Figure 1). Selecting a census block group reveals a detailed view of the information used to calculate the score for that area (Figure 2). Measures of inequality are presented in a matrix that readily enables direct comparison. Also depicted is a graphic that outlines the current canopy cover compared to an aspirational canopy cover for that area. This information enables a relatively detailed look at the environmental justice status of a given urban area, with little time investment.

Assessment of functionality

Tree Equity Score aggregates various data points into a visual format that is both comprehensive and easy to understand. This tool integrates multiple socio-economic and environmental indicators, offering a robust picture of tree canopy cover disparities across urban areas. While the Tree Equity Score provides valuable insights, it has some limitations. Users cannot customise the data layers or indicators shown on the map. The organisation American Forests has predetermined the most relevant factors based on their assessment of what best represents environmental justice, which may streamline the tool but also has the effect of limiting flexibility and customisability. This approach ensures consistency and relevance but may not account for local nuances or additional factors that some users might find important, such as the prevalence of specific environmental pollutants. Despite its limitations, the Tree Equity Score serves several practical

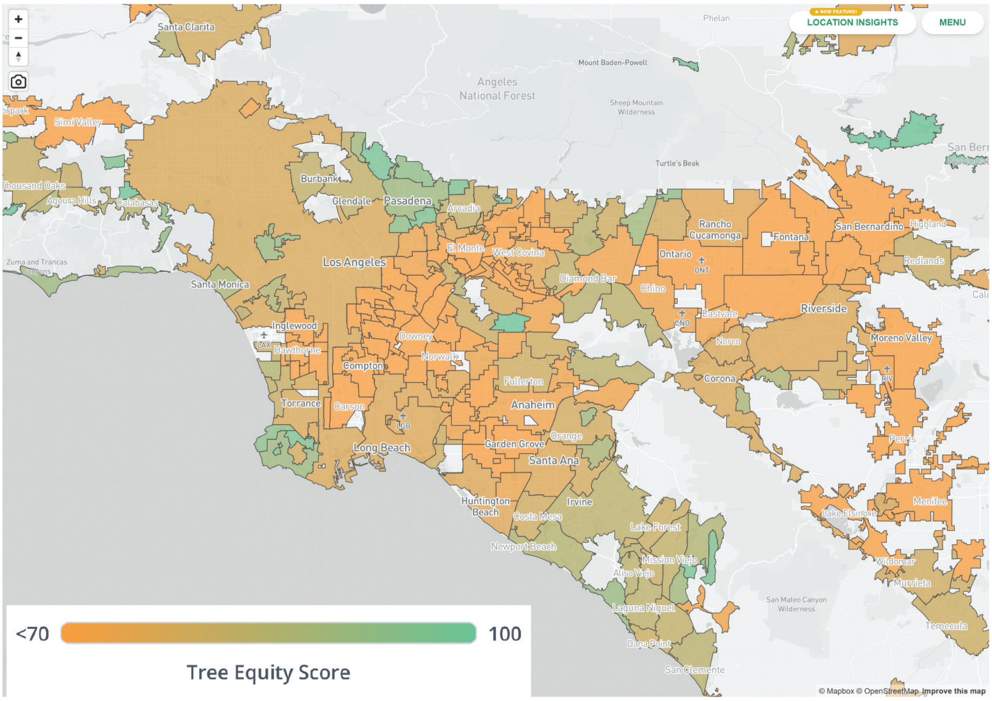


Figure 1. Tree Equity Score evaluation of the greater Los Angeles area, California. (https://treeequityscore.org).

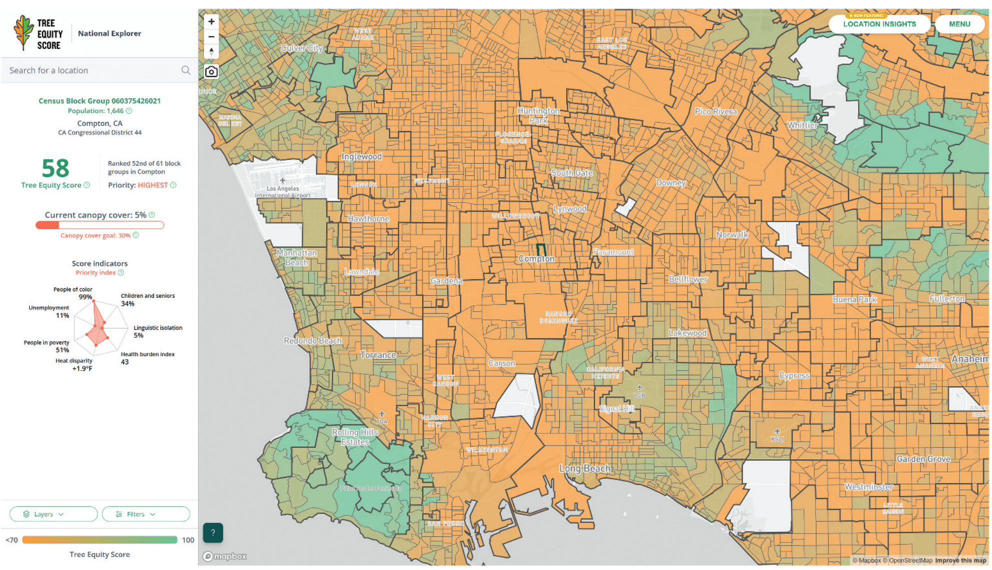


Figure 2. A census-block level analysis produced by Tree Equity Score, depicting inequality matrix in the left menu. (https://treeequityscore.org).

purposes. It provides a relatively quick yet detailed look at the environmental justice status of urban areas, highlighting where intervention is most needed. The accessible interface and clear visuals can help community members and advocates raise awareness about tree equity issues in their neighbourhoods. Overall, Tree Equity Score may be best suited to provide an initial evaluation of the environmental quality in an area.

Case study

Tree Equity Score was utilised by the Office of Policy Development and Research within the U.S. Department of Housing and Urban Development to assess the relationship between the presence of Housing Choice Voucher Households in a community and the Tree Equity Score (i.e. aggregate score that considers socioeconomic situation alongside canopy cover) of that community (Din & Krisko, 2022). The Housing Choice Voucher programme is a federal rent subsidy programme for LMI families located in private rentals. Housing Choice Voucher (HCV) households are more frequently found in LMI neighbourhoods, which tend to have lower urban tree canopy cover and less green infrastructure (Locke et al., 2021). Din and Krisko (2022) analysed Housing Choice Voucher and Tree Equity Score data from Boston, MA; Los Angeles, CA; New York City, NY; Portland, OR; Seattle, WA; and Washington, D.C. The study concluded that in all the cities except Boston, MA, Tree Equity Scores were found to be higher in neighbourhoods without HCV households (Din & Krisko, 2022). This report called for more research into the benefits of green infrastructure in low-income neighbourhoods and concluded by stating that,

> Given the wealth of research indicating that HCV households located in low-quality neighborhoods, it is unsurprising that HCV households are not only spatially concentrated in neighborhoods of poverty but also neighborhoods with low tree equity,
>
> (Din & Krisko, 2022)

This report highlights the ability of Tree Equity Score to facilitate a somewhat comprehensive first look at environmental justice in America's most vulnerable neighbourhoods.

EJScreen

Released to the public by the EPA in 2015 and now hosted by the Public Environmental Data Partners (https://pedp-ejscreen.azurewebsites.net/). EJScreen is an environmental justice mapping and screening tool. It allows users to access high-resolution environmental and demographic information for locations in the United States and facilitates state-wide, regional, or national comparisons of their selected locations (EPA 2024). The user interface for EJScreen is a virtual map enabling the selection of a wide range of human health and environmental data. EJScreen users can select indicators that are representative of environmental quality, such as PM2.5 concentration (Figure 3), ozone concentration, and asthma rates. The data are represented on the map using colour shading that facilitates understanding and comparison (Figure 3). In addition to environmental data, EJScreen offers a comprehensive suite of socioeconomic indicators that are integral to understanding the context of environmental justice. These indicators encompass a range of demographic factors that are closely associated with social vulnerability and health disparities. Select (from 26) key socioeconomic indicators provided by EJScreen include:

(1) **Minority Population**: This indicator reflects the percentage of residents within a census block group who identify as a racial or ethnic minority. Understanding the distribution of minority populations is crucial for identifying communities that may be disproportionately affected by environmental hazards.
(2) **Low-Income Population**: This indicator represents the percentage of individuals living below the federal poverty level within a census block group. Low-income communities often have limited access to healthcare, education, and other resources, making them more vulnerable to environmental risks.
(3) **Linguistic Isolation**: This indicator captures the percentage of households where English is not the primary language spoken by individuals over the age of 14. Linguistically isolated communities may face barriers in accessing information about environmental risks and participating in public decision-making processes.
(4) **Population with Less Than High School Education**: This indicator measures the percentage of individuals aged 25 and older who have not completed high school. Lower educational attainment is often associated with reduced health literacy, which can affect a community's ability to understand and respond to environmental threats.
(5) **Unemployment Rate**: This indicator represents the percentage of the civilian labour force that is unemployed. Higher unemployment rates can contribute to economic stress and limit a community's capacity to mitigate environmental impacts.

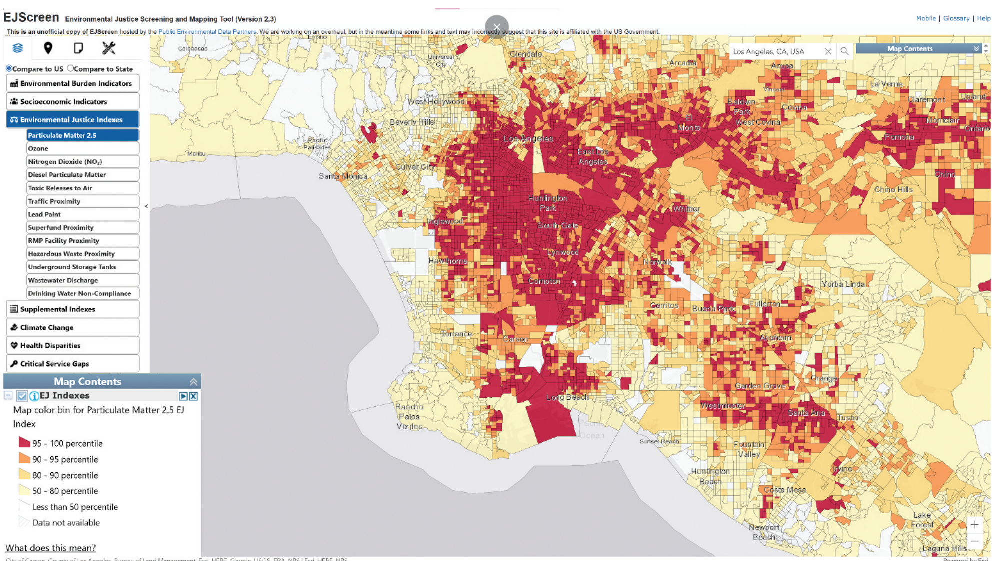


Figure 3. Analysis of PM2.5 for the city of Los Angeles, California, the surrounding area. (https://pedp-ejscreen.azurewebsites.net/).

(6) **Age Indicators**: This indicator represents the percentage of the population that is under 5 years old or over 64 years old. These age groups are often more susceptible to environmental hazards, with children and the elderly being at greater risk of health complications from pollution.

These indicators are used alongside demographic data to generate a Demographic Index and Environmental Justice Indices. The Demographic Index is calculated for both individual census blocks and nationwide. Demographic index values for each block are compared to the value for the state, or for the United States as a whole, and then multiplied with both the selected environmental indicator and the population of that census block producing each Environmental Justice Index. Environmental Justice Indices are a key feature of EJScreen and assist the end-user in identifying concerns relative to a wide range of purposes, including educational programmes, policy formation, and grant writing (EPA, 2024).

Case study

EJScreen was utilised in a case study examining environmental justice in Richmond, Virginia (Mital, 2023). The intent of this study was to determine if the change in environmental quality from 2015 to 2021 was significantly different between historically redlined and non-redlined communities (Mital, 2023). EJ scores for Particulate Matter 2.5 Concentration (PM2.5), Ozone Concentration, and Wastewater Discharge Levels were assessed at the Census Block Group level using EJSCREEN. Mital (2023) delineated neighbourhoods based on their Homeowner Loan Corporation (HOLC) neighbourhood grade to examine the effects of redlining, where minority and low-income communities were systematically denied access to mortgage financing and investment, leading to a lack of resources for infrastructure and environmental management. It was found that scores for PM2.5 Concentration were worse in lower-graded (C and D) neighbourhoods compared to more desirable (A and B) neighbourhoods from 2015 to 2021. This study also found that those same lower-graded neighbourhoods also suffered higher ozone concentrations. Based on these conclusions, Mital (2023) determined that due to the ability of trees to sequester pollutants, "Community-led tree planting efforts may also be helpful in improving formerly redlined communities' PM2.5 and Ozone EJ scores (p. 13)." This study concludes with a call for the city of Richmond – which may also apply more broadly to other communities – to "increase its tree canopy and, as a result, decrease PM2.5 and Ground-level Ozone concentrations in the city's historically redlined communities" (Mital, 2023).

Assessment of functionality

One of the standout features of EJScreen is usability. The tool features a user-friendly interface that streamlines the process of accessing and interpreting complex environmental and demographic data. Its straightforward design ensures that users, regardless of their level of expertise, can navigate the platform with relative ease. With a few keystrokes, users can readily access up-to-date environmental and demographic data for their community in a short period of time.

Critiques of EJScreen have included speculation as to its ability to accurately assess environmental justice in its totality due to the use of select metrics regarding environmental inequality. EJScreen lacks measurements for canopy cover and access to greenspace, which are known to be lower in redlined areas (Nowak, 2020). According to Mullen (2022), of the twelve environmental indicators, ten relate to air quality measures. The gaps present in relation to canopy cover, urban tree canopy cover and access to greenspace may not adequately inform decision-makers and practitioners about legitimate environmental justice grievances, allowing the potential for situations to go unaddressed.

CalEnviroScreen

CalEnviroScreen (https://oehha.ca.gov/calenviroscreen) was developed in 2013 by California Office of Environmental Health Hazard Assessment (OEHHA) on behalf of the California Environmental Protection Agency (CalEPA) to identify communities affected by pollution and other environmental hazards (Figure 4). It was developed with the intent of providing information to guide allocation of the state's resources, seeking to measure the "cumulative impact" of environmental and socioeconomic factors on the residents of California. The CalEPA defines cumulative impact as:

> … exposures, public health or environmental effects from the combined emissions and discharges, in a geographic area, including environmental pollution from all sources, whether single or multi-media, routinely, accidentally, or otherwise released. Impacts will take into account sensitive populations and socioeconomic factors, where applicable and to the extent data are available.
>
> (OEHHA, 2021)

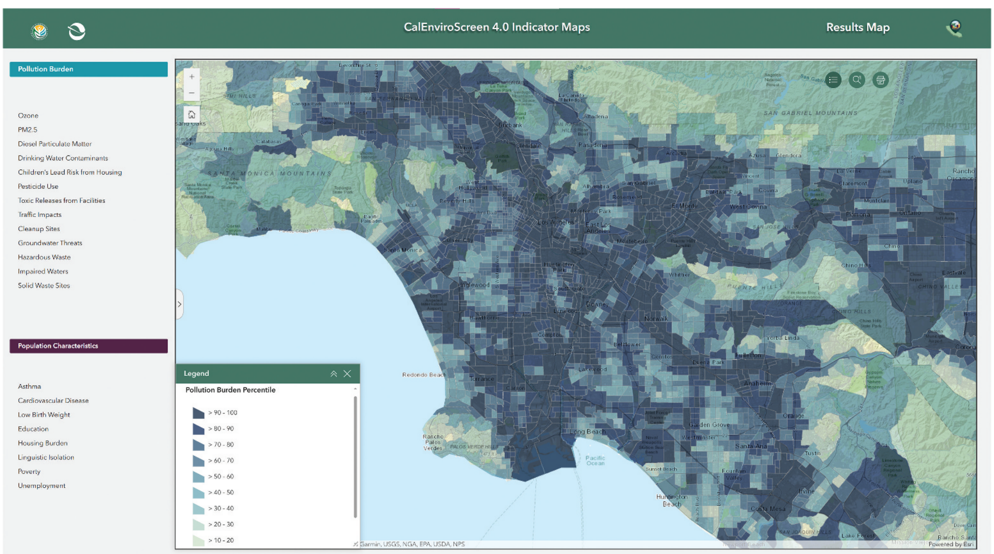


Figure 4. Analysis of pollution burden with darker areas indicating a higher level of burden in Los Angeles, California. (https://oehha.ca.gov/calenviroscreen).

To achieve this, CalEnviroScreen features measurements of twenty-one indicators, grouped into two main categories – pollution burden and pollution characteristics. Pollution burden describes exposure data, such as PM2.5 and ozone concentrations, and environmental effects like impaired water bodies and hazardous waste facilities. Population characteristics, features measures of sensitive populations, such as those suffering from asthma and low birthweights, as well as socioeconomic factors, such as unemployment, poverty, and educational attainment. Through the examination and analysis of these categories, a more comprehensive evaluation of environmental justice in the state of California is ascertained. These data are presented using an online map with values displayed at the census-block level. The census blocks are colour-coded based on the severity of the cumulative impact that residents face. The severity is determined by scoring each of the measured impacts based on percentile and then scaling the scores to ensure that pollution burden and population characteristics are weighted equally.

Case study

A study conducted by Greenfield et al. (2017) at The University of California Berkeley examined the spatial relationship between environmental hazards, socioeconomic hardships, and health outcomes. The intent of this study was to determine if CalEnviroScreen was accurately depicting these relationships with their mapping tool. Data from CalEnviroScreen was gathered, alongside hospitalisation rates for fourteen ICD-9 disease categories according to zip code. Principal component analysis revealed strong associations between CalEnviroScreen data and environmental, socioeconomic, and health outcome variables (Greenfield et al., 2017). While both environmental and socioeconomic principal components were significantly associated with disease burden, socioeconomic factors contributed more substantially to explaining variation in disease burden. The study identifies CalEnviroScreen's efficacy for identifying areas of high environmental exposure and population vulnerability, while also suggesting that socioeconomic status may exert a greater influence on disease burden compared to environmental pollutant exposure (Greenfield et al., 2017).

Assessment of functionality

Housing both the thorough evaluation of environmental data similar to that provided by EJScreen, with the user-friendliness of Tree Equity Score, CalEnviroScreen exists at the intersection of accessibility and precision. CalEnviroScreen's chosen range of indicators allows for a more holistic comprehension of the designated areas of the environmental justice landscape. Each census block has an informative pop-up menu that provides concise measurements for all indicators. Each indicator also has a link to an informative page that explains the importance of that measurement in accessible language, allowing for a wider audience to access and make use of this powerful tool. An important limitation associated with CalEnviroScreen is that it does not consider green infrastructure. While some of the positive effects of greenspace may be considered and measured – the presence of green infrastructure and its positive influence on concentrations of PM2.5 and ozone, as well as asthma-related emergency room visits – the lack of a distinct measurement of greenspace does limit the usefulness and applicability of this tool.

ParkServe/ParkScore

ParkServe (https://parkserve.tpl.org) is a tool developed in 2017 by the Trust for Public Land (TPL), a non-profit organisation based in the United States, that maps and assesses park access across cities and communities nationwide (Figures 5 and 6). It provides a detailed mapping tool that allows users to visualise and analyse park access at a granular level. ParkServe offers insights into the percentage of a city's population that lives within a 10-minute walk of a park, with data categorised by age, income, and race/ethnicity. The tool also overlays comprehensive demographic data, including household income and language proficiency, as well as climate-related information. ParkServe is closely related to ParkScore, another TPL tool, as it supports the analysis used in ParkScore's rankings by providing the underlying data and mapping capabilities that inform the evaluation of park systems across the country. Together, these tools help to identify and address disparities in park access and promote equitable greenspace development.

Case study

ParkScore was used as the basis for a study to better understand disparities in access related to greenspace across 99 of the 100 most populous municipalities in the United States (Rigolon et al., 2018). This study was conducted jointly by the U.S. Forest Service and the University of Illinois to examine how the quality of urban park systems, measured through their ParkScore, may vary depending on a city's median income and demographics. In Los Angeles, it was found that neighbourhoods with a median income above $100,000 had nearly twice the park access compared to neighbourhoods with a median income below $30,000 (Rigolon et al., 2018). They concluded that

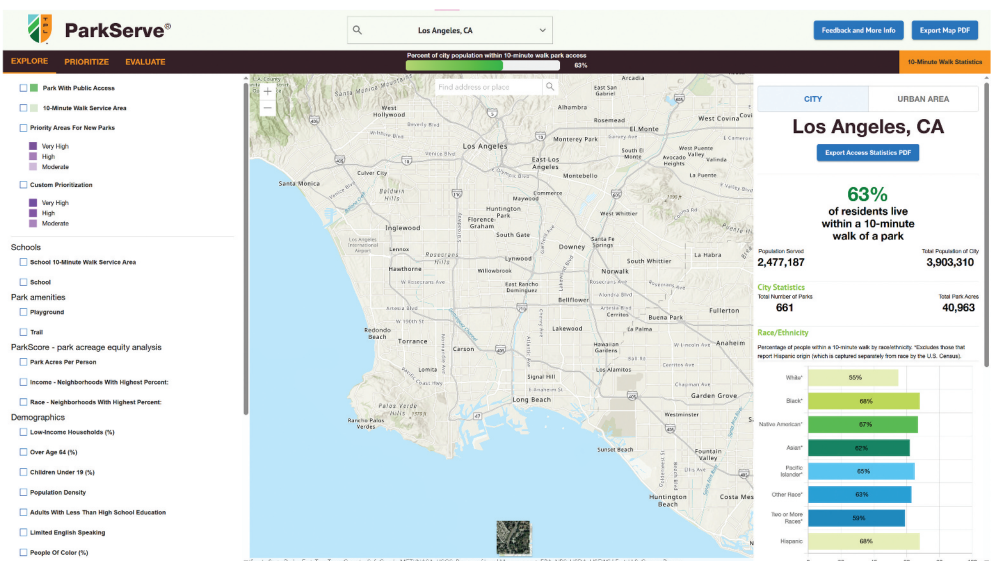


Figure 5. ParkServe map, Los Angeles, California. (https://parkserve.tpl.org).

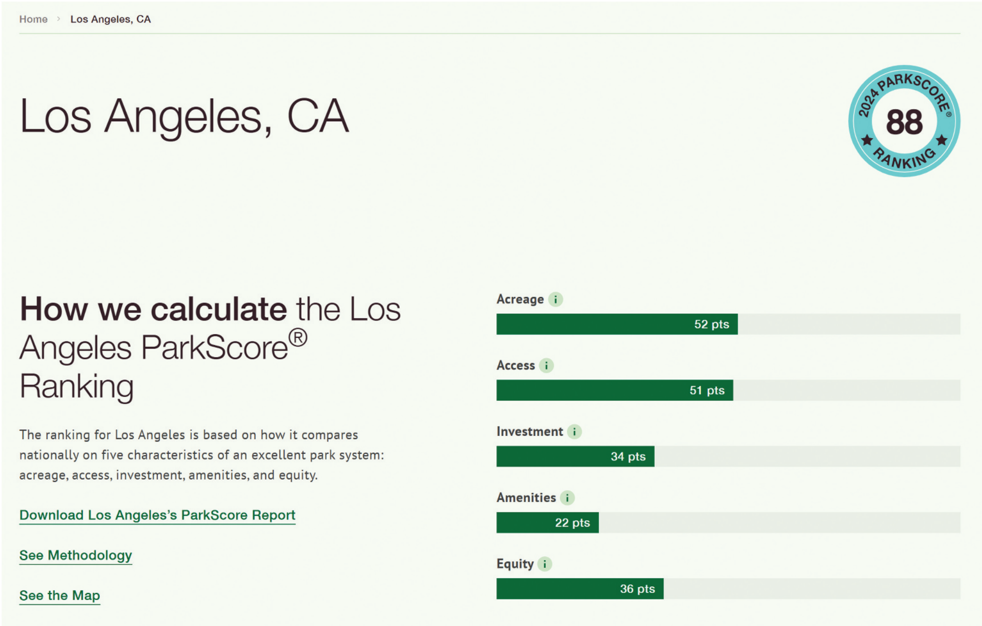


Figure 6. ParkScore scoring legend, Los Angeles, California. (https://www.tpl.org/parkscore).

> … affluent majority-White municipalities have higher quality park systems than those with larger concentrations of low-income ethnic minority people, and predominantly Latino cities are more disadvantaged than predominantly Black municipalities. We also uncovered cities with higher shares of Latinos have significantly higher neighborhood-level socio-economic inequities in walking access to parks than cities with lower percentages of Latino residents. (p. 9)

These findings echo other studies' conclusions that affluent, White neighbourhoods consistently have greater access to higher-quality greenspace, and thus derive a disproportionate share of the myriad of health benefits associated with green infrastructure.

Assessment of functionality

ParkScore generates an easy-to-use metric that enables both an initial evaluation of a city's public greenspace as well as a more complex understanding of the state of a city's environment. With the "10-minute walk" feature, users can quickly visually represent disparities in relation to access to parks. ParkServe also generates possible sites for new parks that would quantifiably remedy park access-inequalities in relation to the largest number of municipal households. In addition to park-related data, the user can overlay some environmental and health data to further outline inequalities that are experienced at the street level. ParkServe also allows users to readily create and share professional-looking, data-driven maps of their neighbourhood's public greenspace share information via an "Export Map PDF" button. Unfortunately, the ParkScore suite does not provide measurements related to street trees or urban tree canopy cover.

I-Tree tools

The i-Tree (https://www.itreetools.org/) suite of tools was developed by the USDA Forest Service (USDA FS) in collaboration with the Davey Tree Expert Company, the Arbor Day Foundation, the Society of Municipal Arborists, the International Society of Arboriculture, and Casey Trees (Nowak, 2020). Launched in 2006, i-Tree was designed to provide urban forestry professionals with a reliable, accessible means to quantify the benefits and values of trees in urban settings in USD. The development of i-Tree was driven by the need for a comprehensive tool that could support urban forest management and planning through detailed analyses of tree populations and their ecological contributions (Nowak, 2020). Since its inception, i-Tree has expanded to feature a variety of analysis tools, each designed to address specific aspects of urban forest management. Among the tools available, i-Tree Eco is the flagship, known for providing detailed analyses of urban forests, including ecosystem services like air pollution removal, carbon sequestration, and stormwater interception. i-Tree Canopy offers a quicker way to estimate tree canopy cover using aerial images, while i-Tree Hydro focuses on modelling the effects of vegetation on urban hydrology. i-Tree Species assists in selecting tree species based on environmental needs, and i-Tree MyTree is a mobile tool that allows individuals to estimate the benefits provided by individual trees. Lastly, i-Tree Design is geared towards homeowners and small-scale projects, enabling users to plan tree plantings and estimate their future benefits.

I-Tree landscape

i-Tree Landscape stands out among the i-Tree tools for its integration of tree canopy data with demographic, environmental, and health data, providing users with a powerful platform for prioritising tree planting and conservation efforts. Unlike other i-Tree tools that often require field data collection, i-Tree Landscape is a web-based mapping tool and allows users to perform large-scale analyses using existing data layers (Figures 7 and 8).

One of the key features of i-Tree Landscape is its ability to identify areas with low canopy cover, high pollution levels, and vulnerable populations, making it particularly useful for aligning tree planting efforts with environmental justice goals. The tool utilises tree and impervious cover data along with U.S. Census data to create a prioritisation index that highlights areas for tree planting or protection. This index is customisable, allowing users to assign weights to various factors such as future climate projections, land cover, tree canopy benefits, health risks, forest risks, and socio-demographic data including population density, minority population density, and the percentage of the population below the poverty line. This flexibility makes i-Tree Landscape a powerful tool for urban planners and policymakers within the U.S. aiming to address multiple objectives through urban greening initiatives.

Case study

A study conducted in the Bronx, NY, assessed the effectiveness of i-Tree Landscape in prioritising tree planting locations compared to a spatially explicit multi-objective decision

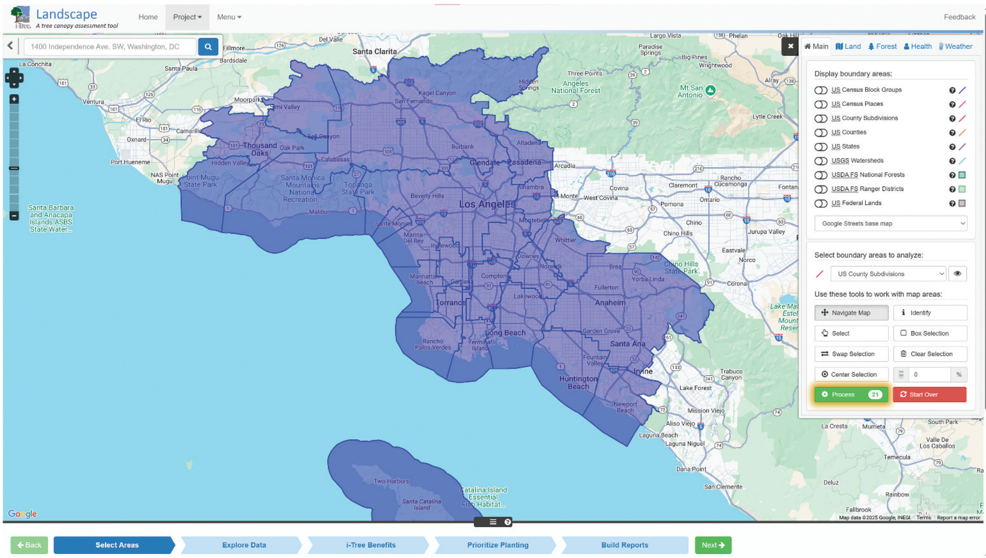
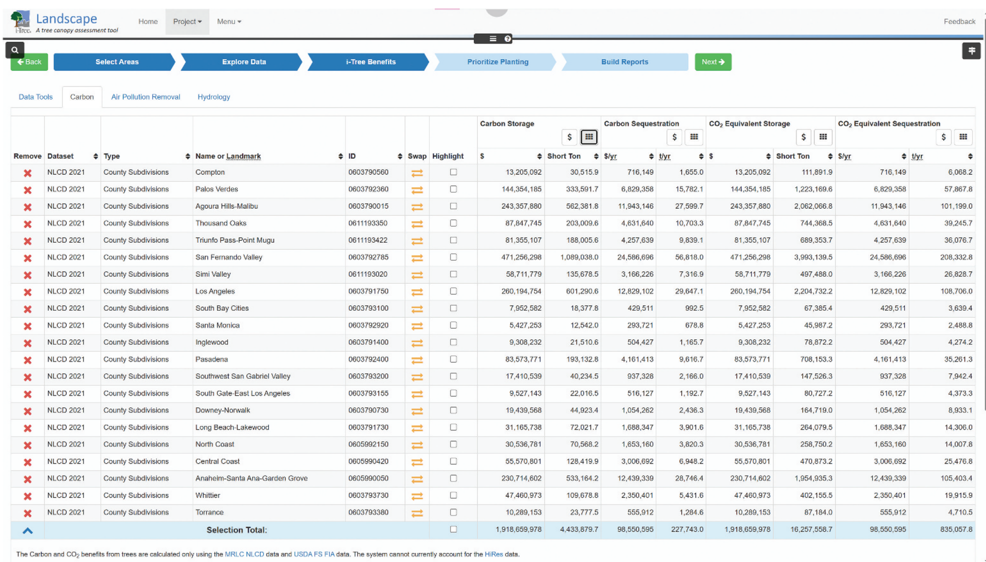


Figure 7. I-Tree landscape selection, Los Angeles, California. (https://landscape.itreetools.org).



Dataset	Type	Name or Landmark	ID	Carbon Storage $	Carbon Storage Short Ton	Carbon Sequestration $/yr	Carbon Sequestration t/yr	CO_2 Equivalent Storage $	CO_2 Equivalent Storage Short Ton	CO_2 Equivalent Sequestration $/yr	CO_2 Equivalent Sequestration t/yr
NLCD 2021	County Subdivisions	Compton	0603790560	13,205,092	30,515.9	716,149	1,655.0	13,205,092	111,891.9	716,149	6,068.2
NLCD 2021	County Subdivisions	Palos Verdes	0603792360	144,354,185	333,591.7	6,829,358	15,782.1	144,354,185	1,223,169.6	6,829,358	57,867.8
NLCD 2021	County Subdivisions	Agoura Hills-Malibu	0603790015	243,357,880	562,381.8	11,943,146	27,599.7	243,357,880	2,062,066.8	11,943,146	101,199.0
NLCD 2021	County Subdivisions	Thousand Oaks	0611193350	87,847,745	203,009.6	4,631,640	10,703.3	87,847,745	744,368.5	4,631,640	39,245.7
NLCD 2021	County Subdivisions	Triunfo Pass-Point Mugu	0611193422	81,355,107	188,005.6	4,257,639	9,839.1	81,355,107	689,353.7	4,257,639	36,076.7
NLCD 2021	County Subdivisions	San Fernando Valley	0603792785	471,256,298	1,089,038.0	24,586,696	56,818.0	471,256,298	3,993,139.5	24,586,696	208,332.8
NLCD 2021	County Subdivisions	Simi Valley	0611193020	58,711,779	135,678.5	3,166,226	7,316.9	58,711,779	497,488.0	3,166,226	26,828.7
NLCD 2021	County Subdivisions	Los Angeles	0603791750	260,194,754	601,290.6	12,829,102	29,647.1	260,194,754	2,204,732.2	12,829,102	108,706.0
NLCD 2021	County Subdivisions	South Bay Cities	0603793100	7,952,582	18,377.8	429,511	992.5	7,952,582	67,385.4	429,511	3,639.4
NLCD 2021	County Subdivisions	Santa Monica	0603792920	5,427,253	12,542.0	293,721	678.8	5,427,253	45,987.2	293,721	2,488.8
NLCD 2021	County Subdivisions	Inglewood	0603791400	9,308,232	21,510.6	504,427	1,165.7	9,308,232	78,872.2	504,427	4,274.2
NLCD 2021	County Subdivisions	Pasadena	0603792400	83,573,771	193,132.8	4,161,413	9,616.7	83,573,771	708,153.3	4,161,413	35,261.3
NLCD 2021	County Subdivisions	Southwest San Gabriel Valley	0603793200	17,410,539	40,234.5	937,328	2,166.0	17,410,539	147,526.3	937,328	7,942.4
NLCD 2021	County Subdivisions	South Gate-East Los Angeles	0603793155	9,527,143	22,016.5	516,127	1,192.7	9,527,143	80,727.2	516,127	4,373.3
NLCD 2021	County Subdivisions	Downey-Norwalk	0603790730	19,439,568	44,923.4	1,054,262	2,436.3	19,439,568	164,719.0	1,054,262	8,933.1
NLCD 2021	County Subdivisions	Long Beach-Lakewood	0603791730	31,165,738	72,021.7	1,688,347	3,901.6	31,165,738	264,079.5	1,688,347	14,306.0
NLCD 2021	County Subdivisions	North Coast	0605992150	30,536,781	70,568.2	1,653,160	3,820.3	30,536,781	258,750.2	1,653,160	14,007.8
NLCD 2021	County Subdivisions	Central Coast	0605990420	55,570,801	128,419.9	3,006,692	6,948.2	55,570,801	470,873.2	3,006,692	25,476.8
NLCD 2021	County Subdivisions	Anaheim-Santa Ana-Garden Grove	0605990050	230,714,602	533,164.2	12,439,339	28,746.4	230,714,602	1,954,935.3	12,439,339	105,403.4
NLCD 2021	County Subdivisions	Whittier	0603793730	47,460,973	109,678.8	2,350,401	5,431.6	47,460,973	402,155.5	2,350,401	19,915.9
NLCD 2021	County Subdivisions	Torrance	0603793380	10,289,153	23,777.5	555,912	1,284.6	10,289,153	87,184.0	555,912	4,710.5
Selection Total:				1,918,659,978	4,433,879.7	98,550,595	227,743.0	1,918,659,978	16,257,558.7	98,550,595	835,057.8

The Carbon and CO_2 benefits from trees are calculated only using the MRLC NLCD data and USDA FS FIA data. The system cannot currently account for the HiRes data.

Figure 8. I-Tree landscape results screen for the area selected in Figure 7, depicting ecosystem services provided by trees. (https://landscape.itreetools.org).

support framework (Nyelele et al., 2022). The results demonstrated i-Tree Landscape's utility in straightforward, single-goal prioritisation, such as PM2.5 air pollutant removal, where it recommended similar census block groups for additional tree cover as the decision support tool. However, when considering multiple objectives, i-Tree Landscape recommended fewer block groups than the decision support framework. The latter's ability to balance multiple goals resulted in a broader and more equitable distribution of tree planting recommendations. i-Tree Landscape's reliance on consolidated county-based models resulted in less precise recommendations compared to the spatially explicit, fine-scale data used by the decision support framework, which impacted the accuracy of prioritisation outcomes. Additionally, Nyelele et al. (2022) found that i-Tree Landscape's approach did not fully account for equity considerations, whereas the decision support framework better identified smaller block groups with limited tree cover but high resident numbers, aligning more closely with equity-focused goals.

Assessment of functionality

While i-Tree Landscape offers a powerful and flexible platform for urban forestry planning, its weighted scoring approach can introduce subjectivity, as it requires decision-makers to determine the contribution of each variable to the overall goal. For example, on the "Prioritize Tree Planting" screen, the user must determine how important each of the factors, "Tree Stocking Level", "Tree Cover per Capita", and "Population Density" are. While some guidance is provided, this subjectivity can limit accessibility, as it necessitates a certain level of expertise and familiarity with a wide range of information. Nonetheless, i-Tree Landscape remains a crucial tool for those seeking to align urban forestry efforts with broader environmental and social objectives (Table 1).

Discussion

Accessible environmental justice analysis tools have the potential to inform both practice and policy in relation to addressing disparities related to greenspace access and environmental quality in urban environments. Tools such as CalEnviroScreen, ParkScore, and i-Tree offer unique functionalities and approaches, each contributing to a more comprehensive understanding of environmental justice issues. While these tools provide valuable insights, their effectiveness is contingent upon their ability to accurately capture and address the multifaceted nature of both the social and bio-physical environment. This requires accurate measurements of a host of ecosystem services and disservices. In addition to accurate measurements, the currency of data used in these tools is equally critical. Urban environments are constantly evolving, and without regularly updated data, these tools may provide an outdated or inaccurate representation of environmental factors germane to environmental justice concerns. Just as urban tree inventories demand ongoing updates – a task

Table 1. Features of each environmental justice mapping tool.

Feature	Tree equity score	EJScreen	CalEnviroScreen	ParkScore	i-Tree landscape
Green Infrastructure Data	✓	X	X	✓	✓
Air Quality Indicators	X	✓	✓	X	✓
Socioeconomic Data	✓	✓	✓	✓	✓
Demographic Indicators	✓	✓	✓	✓	✓
Health Data Integration	X	✓	✓	X	✓
Customizable Data Layers	X	✓	X	X	✓
Open Access	✓	✓	✓	✓	✓
Geographic Focus	United States	United States	California	United States	United States

often constrained by limited resources – so too must EJ analysis tools be continuously refreshed with current data to remain effective. Studies have demonstrated the challenges communities face in maintaining up-to-date urban tree inventories, reflecting the broader struggle of keeping datasets relevant in rapidly changing urban landscapes (Gerrish & Watkins, 2018; Nowak et al., 2014).

CalEnviroScreen stands as a notable example of a tool designed to identify communities disproportionately burdened by pollution and other environmental hazards. By integrating a wide array of indicators encompassing pollution burden and population characteristics, CalEnviroScreen offers a holistic evaluation of environmental justice across California. However, the tool's omission of green infrastructure data represents a notable gap, as greenspaces play a crucial role in mitigating environmental inequalities and promoting community well-being. Similarly, ParkScore provides valuable insights into park quality, access, and size, thereby offering an objective assessment of a city's provision of open-access greenspace. ParkScore's accessibility and user-friendly interface make it a valuable resource for stakeholders and policymakers. Nonetheless, the absence of measurements for street trees and canopy cover limits the tool's ability to comprehensively evaluate greenspace equity, highlighting the need for supplementary data sources and further refinement. In contrast, i-Tree offers a wide range of capabilities for assessing tree benefits and prioritising green infrastructure investments.

Beyond just environmental justice analysis tools, there are lessons to be learned from the range of mapping tools. EJAtlas (https://ejatlas.org/) is a mapping tool that allows users to view major environmental incidents world-wide. This global perspective is valuable, even for those endeavouring to address local environmental challenges. Understanding how disenfranchised peoples across the globe address environmental hardship can offer a new lens through which we can observe our own inequalities. Another valuable perspective offered by a mapping tool is provided by Places (https://www.cdc.gov/places/index.html), a health-based mapping tool provided by the Center for Disease Control. Human health is an essential component of environmental justice, and most EJ mapping tools provide some amount of health-related data. Comprehensive health analyses alongside environmental analyses could help reveal previously unknown links between human health and the environment, as well as further understanding related to green infrastructure, air quality, and health relationships.

Through the analysis of these tools, we can begin to "shop" from their wide range of features to start imagining the next generation of environmental justice mapping. A critically important component that these tools all share is that they are open access. Open access is crucial for empowering communities to participate in environmental justice initiatives (Clayson et al., 2021). Public access to comprehensive environmental data democratises information and enables a broader audience to engage with and advocate for environmental equity. This accessibility ensures that even those without specialised training can access valuable data to inform their community efforts and policy decisions.

Another aspect of these tools, though difficult to quantify, is user-friendliness. The usability and user-friendliness of technology-based tools and suites are fundamental to their widespread adoption and effectiveness (Whatfix, 2024) and this would include environmental justice assessment tools. Tree Equity Score stands out in this regard. Colour-coded maps provide an accessible and quick overview of urban canopy cover disparities. The understandability of the analysis provided by these tools determines their utility in real-world applications. Tools that present data in a clear, visually oriented manner enable users to quickly grasp the extent of environmental inequities. These tools must be designed to minimise the learning curve, making them accessible to a wide range of users, including community activists, policymakers, and researchers. Equally important is the incorporation of feedback from end-users and community members in the development and refinement of these tools. Urban foresters, environmental planners, and practitioners who utilise these tools in their work can provide invaluable insights to improve functionality, address technical challenges, and enhance overall usability. Engaging with community members ensures that the tools reflect local realities and priorities, incorporating factors that might otherwise be overlooked. This participatory approach not only increases the relevance of the tools but also empowers communities by involving them directly in the planning processes that impact their environments (Carmichael & McDonough, 2018; Wolch et al., 2014). Fostering community engagement and incorporating local knowledge and perspectives are crucial for ensuring the relevance and applicability of these tools in diverse urban contexts. A commitment to open access must be maintained. Tool layouts and map design must consider a wide range of technological abilities, as a tool that is not accessible will not be fully utilised (Zhekova et al., 2024). Measurements of the urban forest must be a focal point of the tool, with the ability for communities to supplement existing datasets with citizen-sourced information. By applying what we have learned, the next generation of environmental justice mapping tools can be increasingly powerful, with the potential for substantial implications for grassroots advocacy.

Conclusion

Continued research, collaboration, and refinement of environmental justice analysis tools are essential in advancing efforts to address environmental disparities and in creating greener, healthier, more resilient communities for all residents. Integrating additional indicators, most importantly canopy cover along with other green infrastructure data, and addressing technical limitations will enhance the effectiveness of these tools in promoting environmental justice. By leveraging the strengths of these tools and addressing their limitations, the next generation of environmental justice tools has the potential to greatly empower understanding relative to environmental quality and equity in the urban environment.

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Notes on contributors

Sean Mullen is a graduate student completing a Masters in Forest Resources/Arboriculture in the Department of Environmental Conservation at the University of Massachusetts, Amherst.

Richard W. Harper, PhD., is an Extension Professor of Urban & Community Forestry in the Department of Environmental Conservation. He teaches courses and administers an applied integrated research and extension programme in urban forestry.

David V. Bloniarz, PhD is a faculty member at the University of Massachusetts, Amherst, and director of the Urban Natural Resources Institute (UNRI). His primary work involves technology transfer and research initiatives related to urban natural resource structure, function and value. He works on the development of new tools and technologies that can be utilised by planners, managers and researchers.

J. Rebecca Hargrave, is an Associate Professor in the School of Agriculture, Business & Technology at the State University of New York – Morrisville and a Doctoral Candidate in the Department of Environmental Conservation at the University of Massachusetts Amherst. She teaches courses, conducts applied research and outreach in urban & community forestry.

Olga Kostromytska is an Extension Assistant Professor in the Stockbridge School of Agriculture at the University of Massachusetts Amherst. She received her Masters and PhD. degrees in Entomology from the University of Florida, and conducts applied research and extension on several environmental, insect, and plant-related topics.

ORCID

Richard W. Harper http://orcid.org/0000-0002-9522-4562

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