CHAPTER 6

The Role of Urban Tree Canopies in Environmental Justice and Conserving Biodiversity

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Introduction

Urban trees are an important part of biodiversity in urban areas, from cities to periurban suburbs and exurbs. Trees are often the base or underlying ecological support for other biota since they provide habitat, food, and influence other environmental conditions like temperature and moisture. Urban trees provide diverse ecosystem services for people, too, such as providing shade and cooler temperatures, aesthetic value, increases in sense-of-place and social cohesion, reductions in crime, and improvements to physiological and psychological health and well-being (1–3). In forested biomes, urbanization usually means replacing trees with roads, buildings, and other "gray" infrastructure. In biomes that are not naturally forested, urbanization can mean the addition of trees such as in Salt Lake City, UT, parts of Los Angeles County, or Sacramento and Davis, CA. Managing urban forests for societal and species' needs is therefore highly regionally and city-specific.

Urban trees are foundational for urban biodiversity conservation. They provide habitat for a diverse range of species, from birds and insects to mammals, reptiles, and amphibians. By providing food, shelter, and nesting sites, urban trees can increase the abundance and diversity of other species in urban areas, and thus enhance alpha and beta biodiversity. In fact, in the early 1990s the former director of the Iowa Department of Natural Resources commented on how cities and suburbs provided some of the only habitat for wildlife in midwestern states like Iowa and Illinois because expansive agriculture was inhospitable (4). The connectivity of urban tree canopy (of any type), and urban forest patches in particular, may create ecological variation that contributes to diverse biological community composition (5,6). Overall, urban trees are essential for conserving biodiversity by providing valuable habitat and resources for wildlife (7–9).

The spatial distribution of urban trees is neither uniform nor random. This is because individual people, organizations, and societal rules and norms shape where new trees are planted, where trees are removed, and which trees are protected (10). The fields of urban and community forestry have the goal of discerning the spatial distribution of urban trees, the complexity of managing urban trees, and which communities do or do not steward urban trees and forests.

A guiding theme from this body of work is documenting how urban trees are unevenly distributed, and at different scales. For instance, at the parcel scale, most urban land is residential. At the neighborhood scale, higher-income areas have more tree canopy cover than lower-income areas (11,12), and predominantly White neighborhoods have more canopy cover than predominantly Black

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neighborhoods (13). A long-term view reveals the legacies of institutionalized racism (particularly the policy of "redlining") (14) on present-day distribution of urban vegetation generally (15) and urban tree canopy cover in particular (16–19). There are, of course, nuances in how these relationships among income, wealth, and race at the household, neighborhood, and municipal scales unfold. Regardless, these patterns demonstrate important interactions among income, wealth, race, and canopy cover which typically lead to higher-income areas having more trees and communities of color having fewer. How urban trees are managed has important implications not only for conservation but also for distributional and procedural environmental injustice.[1] Indeed, urban trees were the first and are probably the best understood dimensions of inequities in urban conservation.

We have four goals here: (1) introduce and describe urban forestry, (2) explain why other disciplines might be interested in urban forestry, (3) illustrate how wildlife biologists can use urban forestry in their studies, and (4) encourage conservationists to think mechanistically about how urban vegetation, environmental justice, and urban wildlife may interact. Here we describe urban forestry, which requires us to differentiate among different parts of an urban forest: street trees, forested patches, and public vs private ownership. This differentiation is important because these different components of the urban forest are managed by different individuals and organizations, with diverse and sometimes competing interests and authorities. We also explain why other urban biodiversity researchers and practitioners may be interested in urban forestry, measuring urban forests, and investigating how urban vegetation relates to species distributions, composition, and biology. Finally, we illustrate how history matters and how urban forests and environmental justice might look in the future.

[1] Hoover's and Scarlett's chapter discusses the differences between distributional and procedural (in)justice in urban conservation.

Urban forests are spatially and socially heterogeneous: ownerships and management vary over small geographic areas

Urban forestry is the practice of planting, managing, and conserving trees and other vegetation in urban and suburban settings. It ranges from a disciplinary to a transdisciplinary field that can draw on botany, horticulture, urban planning, geographic information science, environmental sociology, and diverse other sets of expertise. Urban forestry aims to increase environmental quality by providing shade and mitigating heat, controlling stormwater runoff, beautifying the landscape, reducing crime, and providing opportunities for community stewardship. In doing so, this practice creates a healthier and more sustainable urban environment for people and, often, other species.

Urban forestry is a critical component of urban ecology, which is the study of how organisms interact with the built environment, including people.[2] Urban forestry is gaining popularity among elected officials via the rise of "million trees" campaigns, citywide tree canopy goals (often in response to increasing weather extremes), and other ambitious tree planting programs (20–25). For example, Beijing added 50 million trees in just four years (26). The entire urban forest consists of individual trees and tree clusters managed by different entities, for different purposes, and with different outcomes (27). We emphasize that an urban "forest patch" is an aggregation of trees, also called a forested natural area or urban woodland. But a forest patch may comprise a mixture of trees in a park or several trees in abutting residential properties, yet the various trees in this latter kind of patch occur on different parcels and thus have different managers. In urban areas, most of the land is privately owned and residential. Thus, conservation goals must be aligned with the relevant authority and desires of those who can manage particular urban trees.

Residential lands: As are the cities and suburbs that harbor them, urban forests are heterogeneous in many ways (Figure 6.1). In forested biomes where

[2] Lambert's and Schell's chapter briefly details the history of urban ecology and conservation.

Figure 6.1 Within the City of Baltimore (a), each parcel of land has a distinct owner. In Baltimore, like most urban areas, most of the land is privately owned (b). There are diverse types of public and private land (c), and different owners have different motivations, capacities, and interests. Land ownership says nothing about land cover. High-resolution, high accuracy, 12-class land cover from the Chesapeake Conservancy and partners shows the spatial heterogeneity of land cover (d). The mixes of ownership and cover define constraints and opportunities for urban forestry.

urbanization has occurred, trees live on all different types of land with varied types of ownerships. One of the most clear and consistent findings from dozens of tree canopy assessments in North America using high-resolution ($\leq$1 m^2) high-accuracy ($\geq$95%) tree canopy maps, is that (1) most land is private residential, (2) most of the tree canopy is private residential, and (3) most of the opportunities for additional tree canopy are also on private residential land. In New York City, for example, there are approximately 750,000 private residential landowners or "forest owners" (28). Each owner may have different motivations, capacities, and interests for tree management, which raises exciting questions about human motivations for urban nature[3] and also complicates managing urban ecosystem services and biodiversity.

Street trees: Street trees have been heavily studied by urban foresters and arboriculturalists (29). These are also the components of urban forests that people probably most commonly experience. Street trees are species diverse because tree populations often consist of locally native species and imported horticultural varieties (30,31). In contrast to residential land, which is managed by numerous landowners, there tends to be one or few organizations charged with managing street trees in a given municipality. The agency responsible for street trees is usually a city's Parks Department, but it is not uncommon to be located within Departments of Transportation or Public Works. Each agency has its own mandate, history, and competing internal priorities and vies for funding with other departments. Understanding how a particular city's government and governance operate is essential to managing street trees for conservation goals. Our experience shows that convincing a mayor or parks department commissioner of the value of street trees is an entirely different task than trying to understand tens of thousands—or hundreds of thousands—of individual residential landowners and their management objectives for their front and back yards. Without people, there would be no street trees. The entire lifecycle of street trees from seed or clone, to a nursery, to a sidewalk, and ultimately until it is removed via chainsaw, chipped, and hauled away is done by and for people. These attributes make street trees a unique component of urban forests.

Parks, open spaces, and forested natural areas: Trees in parks and other open spaces are another important and often-studied part of the urban forest. Many parks have isolated trees or clusters of trees in grassy open areas with little or no competition from other trees which can influence the management needs with respect to conditions like water. There is growing interest in individual trees' and forested areas' performance from a stormwater management perspective (32,33). Forested natural areas, sometimes called urban forest patches, natural area forests (34), and/or urban woodlands (35), bear many similarities to forests in nonurban areas with respect to species composition and structure (35,36). Forested natural areas have spontaneous regeneration, dead material is left to decompose, and, although located within the built environment, they are largely left undisturbed (34,35). Forested natural areas face threats particularly from invasive understory plants and vines (but also pest insects and pathogens) and pressure from herbivory (e.g., from deer and other ruminants).

Patches can and do cross multiple property boundaries, representing additional complexity for management. In the greater Boston area, for example, there are more backyard forested patches and a greater forest patch area than in all public parks combined, in part because there is so much residential land (6,37). From an organismal perspective, a backyard forest patch is a single functional unit. But from a management perspective, in the case of a patch crossing multiple parcel boundaries (like several abutting vacant lots) the threat to development is not the same. A contiguous patch of forest in an Olmsted-designed park like Druid Hill Park in Baltimore City does not face the same development pressures or risk as do two dozen smaller parcels owned by 24 different people—even though as forested patches they may both have similar size, species, structure, and age. Further, multiple levels of government agencies own and manage open spaces and/or forest patches within a city. Visitors to patches on New York City parkland find a sense of refuge, place attachment,

[3] Larson's and Brown's chapter reviews how different human motivations shape how society manages urban habitats and biodiversity.

and experiences with nature (38). Whereas, those living adjacent to some forest patches in Baltimore City are largely ambivalent about patches. The use and experience of urban forest patches warrant further attention among researchers and practitioners. Forested natural area governance is complex and varies geographically (39), especially with multi-parcel forested natural areas. A growing trend in urban conservation are urban land trusts which can buy land, sell the development rights, and protect forested areas from being developed.

Trees on residential properties, street trees, and trees in parks (both in natural areas and on lawns) with different owners and associated motivations reflect just a few different examples for how trees' site-level contexts, ownership, and management interact to provide a different biological template for other organisms. The intersections of ownership, management, and biological context explain, in part, the social and spatial heterogeneity found in US cities' urban forests.

Environmental injustice

The spatial distribution of the urban forest not only relates to insects, birds, mammals, and other wildlife, but also to people. As briefly mentioned earlier, one of the most clear and consistent findings from urban forestry is that (1) higher-income areas have a higher tree canopy cover than nearby lower-income areas (11,12) and (2) communities of color tend to have less tree canopy cover than White areas of cities and suburbs (13). Although such patterns are increasingly being demonstrated in other aspects of urban biodiversity (40), urban forestry has paved the way in understanding the linkages between class and racial inequities and urban nature. Because of the diverse benefits and ecosystem services provided by trees to people in urban areas, the uneven distribution of canopy coinciding with segregating communities along multiple indicators of social status, race, and ethnicity in urban areas produces a distributional environmental injustice.[4]

[4] Hoover's and Scarlett's chapter discusses different forms (e.g., distributional vs procedural) of justice and its relationship to urban environments, including trees.

Understanding patterns of environmental injustice requires understanding processes of environmental injustice over time. Trees do not mature instantly (10), and substantial research shows that historic demographic data predict the present distribution of tree canopy cover (41,42). Bluntly, we do not get to recreate the urban forest every few years; addressing environmental injustice today will matter today and tomorrow. The uneven distribution of trees and urban vegetation in general (14), street trees (30), and tree canopy cover (16–19) today may be an example or result of structural racism (14), as the distribution relates strongly to the history of the racist government practice of redlining and disinvestment in certain neighborhoods. This disparity demonstrates a lack of access to the benefits of urban trees, such as improved air quality, thermal comfort, and stormwater retention, for those living in lower-income neighborhoods. Likewise, household income and wealth do not occur instantly, and the long-term interactions among race, income, and wealth and their consequences for ecological systems need to be understood to address contemporary inequities in urban trees. To address these issues, some state and city governments have begun to invest in programs to promote equitable tree planting and species diversification in order to ensure environmental justice for all their citizens. Yet a recent analysis of more than 100 urban forest management plans in the US shows most plans only briefly mention environmental justice (43).

Along with tree canopy in general and street trees, the distributions of parks and open spaces—and their urban forest patches—also vary by the socioeconomic status of residents. For instance, studies across 10 US cities found that income and education showed strong positive relationships with urban woody vegetation like trees, whereas tree cover was lower in neighborhoods with more Latino, Black, and Indigenous households, and areas with lower percentages of individuals without high school degrees (44). A national synthesis of all publicly accessible open space shows that (1) areas with higher home value have more park access, except in the Northeast; (2) areas with lower income inequality have greater park access; and (3) higher unemployment is associated with greater park access (45).

Given the inequities in the street tree distribution, tree canopy cover, and park access, and the recognition of multiple benefits of urban trees, the 3–30–300 rule has been proposed. Briefly, the 3–30–300 rule proposes that nature exposure from seeing nature, exposure from living among vegetation, and accessing and recreating in green space each provide benefits for human well-being. Therefore everyone should be able to see, "3 trees from every home, school, and place of work," live in a neighborhood with 30% tree canopy cover, and be within 300 meters of the nearest park (46). There is a need to develop the methods for measuring these heuristics and implementing the guidelines, aside from measuring tree canopy at the neighborhood level, which is now well-worked out.

Global perspectives—climate change and the world's urban forests

Human-caused climate change is an ongoing threat to Earth's life support system. Urban forests are poised to help buffer society and biodiversity from some impacts of climate change such as extreme heat and flooding. Yet those urban forests themselves are also threatened by climate change. Research has found that 70% or more of urban tree species found in cities on every continent except Antarctica are at risk from altered temperature and precipitation patterns (47). The situation is worse for equatorial or low-latitude cities where potentially all urban tree species are at risk. The climate threat is active and present given that this research found that over half of urban tree species are currently already exceeding their natural temperature and precipitation regimes and 20%–40% of urban forest tree species around the world are expected to be at enhanced risk from climate change in the places where they are planted by 2050. This threat underscores an urgent need within cities and across cities and regions globally to invest in climate-resilient urban forests. Although urban forests are touted for their ability to buffer impacts of climate change like extreme heat, those same stressors may themselves threaten the world's urban tree canopies. Yet, there are also new frameworks for urban forestry that use climate analog species to help planners plant trees that are more resilient to changing climate conditions (48). These climate analogs can begin accounting for the future temperature, precipitation, and pest/pathogen stressors brought with climate change while also considering aesthetic and biodiversity needs. Such climate analogs may not necessarily be tree species that are native to a region and so planting climate analogs in an urban forest may conflict with some conservation goals that focus on native biodiversity. Conservation practitioners working with urban planners and community groups will have to grapple with a focus on native tree species that may succumb to climate changes and the reality that a non-native climate analog tree may better persist. Even so, depending on the geographic region, there may be opportunities for using assisted migration to plant "native" species from more climate-resilient portions of their range.[5] Ultimately, in many cases around the globe, a tree is likely better than no tree in supporting urban biodiversity and society. Given the need for cities to be hospitable to most of humanity and to play an active role in regional and global conservation efforts, a climate-resilient urban forest is more imperative than ever.

Putting trees on the map

Managing the urban forest and all the biodiversity and communities reliant on those trees necessitates understanding where those trees are, and where they are not. The clear and consistent findings with respect to tree canopy at the neighborhood scale and income and race would not be possible without tremendous innovations in mapping tools. The advent of high-resolution ($\leq$1 m^2), high-accuracy ($\geq$95%) land cover mapping (Figures 6.1 and 6.2) has allowed urban forestry to produce incredible maps of the urban tree canopy and prioritize equitable conservation measures (49–54). Until these recent innovations, urban forestry—and indeed urban ecologists more broadly—relied on coarse, "mid-resolution" mapping data. Prior mid-resolution mapping data were often at resolutions of 30 m^2. In practice, this coarse resolution made

[5] Spotswood et al.'s chapter discusses translocations and assisted migration as a powerful tool for urban conservation.

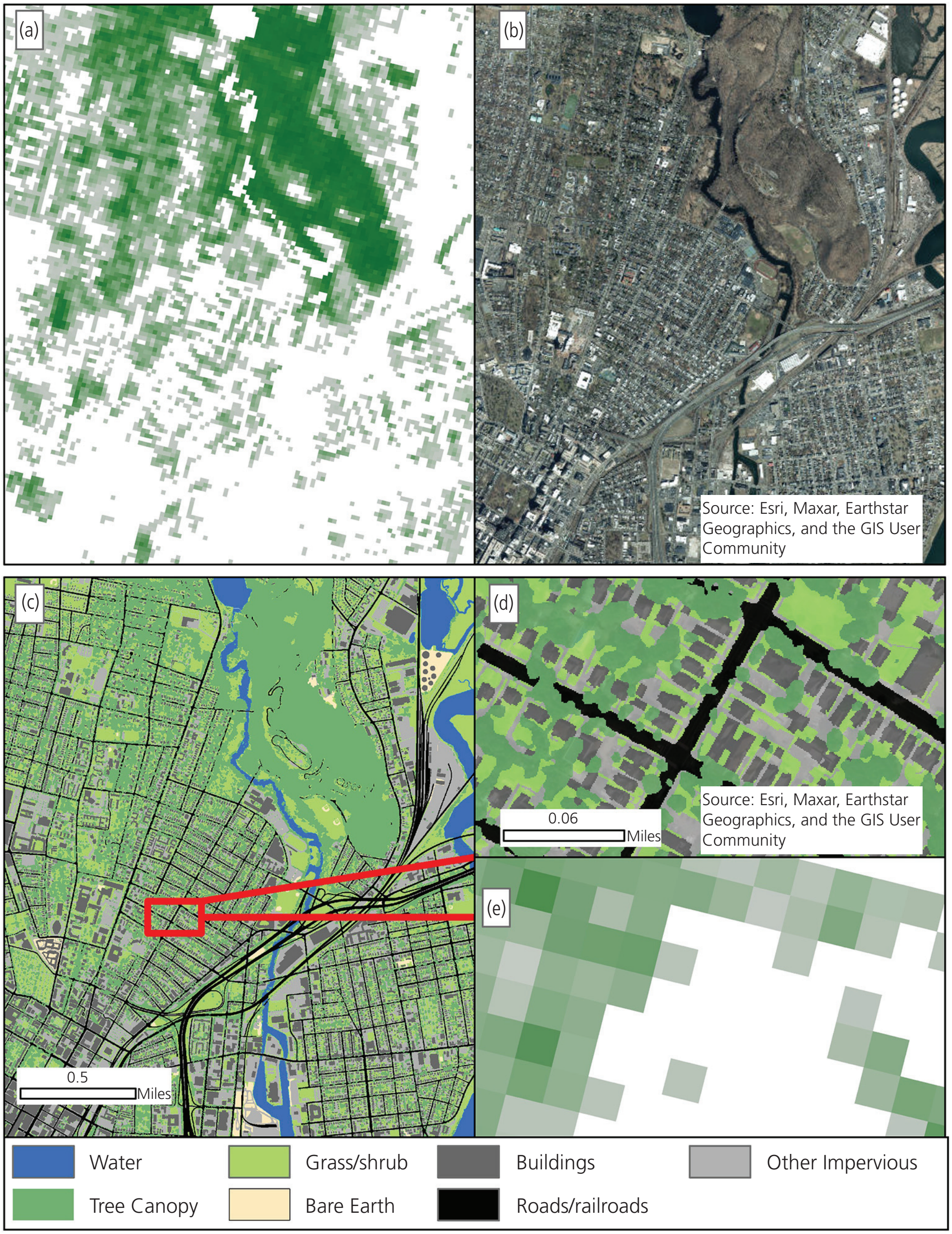

Figure 6.2 New Haven, CT: mid-resolution, Landsat-derived (30 m^2) estimates of tree canopy from the Multi-Resolution Land Characteristics Consortium (https://www.mrlc.gov/data/type/land-cover) miss key patches of urban tree canopy (a) when compared to imagery (b). High-resolution (1 m^2), high-accuracy ($\geq$95%) land cover created by the University of Vermont for the South Central Regional Council of Governments (https://scrcog.org/) has higher categorical resolution as well (c). Zooming in (d) shows small and large street trees planted by the Urban Resources Initiative (https://uri.yale.edu/) and maintained by the City of New Haven, and trees in abutting residential backyards. The same area (e) when mapped with 30-meter data simply fails to capture human- and wildlife-relevant tree canopy.

it impossible to meaningfully map vegetation at a practical scale for management.

Take for example trees along a backyard fence, then a raised bed garden, followed by grass, then the building footprint, a grassy front yard, a sidewalk with street trees, and then the road. All of that spatial heterogeneity—ecologically and socially—would be represented by one single number in prior datasets, despite being several distinct management zones. Worse, often a 30-m^2 pixel covers multiple owners' properties. Whereas these prior, coarse data could not map where vegetation was and where it was needed, newer mapping tools provide trees, other vegetation, and various built features like houses or roads at the parcel scale. As described earlier, most trees and most opportunities for tree management are on residential land—which are relatively small urban parcels—and so prior data could not match the management units due to size mismatches between parcels and pixels.

The now-industry standard land cover data are created by a handful of universities and private companies, and their partnerships. Examples include Virginia Tech (55), UC Davis (37,56,57), the University of South Florida (58–62), and American University (63–66). Private firms routinely creating high-resolution urban tree canopy maps include PlanIt Geo (https://planitgeo.com/) and Earth Define (https://www.earthdefine.com/). The Spatial Analysis Lab at the University of Vermont (UVM) is the leader in this area (https://www.gisforscience.com/chapter11/v2/) and has completed 87 land cover and/or tree canopy change maps, covering 53 million acres, with 1.4 trillion classified pixels (https://uvm.maps.arcgis.com/apps/webappviewer/index.html?id=fe15424caceb4dd294be816581ec2d77).

For example, the standard data from the UVM have seven classes: tree canopy, grass/shrub, bare soil, water, buildings, transportation (roads/railroads), and other impervious surfaces (parking lots, sidewalks, etc.). The Chesapeake Bay Program's freely available watershed-wide maps span roughly 200 jurisdictions at a 1-meter resolution (https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/). UVM is a core partner on that project. Those data contain trees over roads, trees over buildings, and trees over other impervious surfaces so that the user can flexibly combine tree canopy subclasses or impervious subclasses to match the analytical needs of the questions asked. Government agencies also create similar data. For example, the Washington Department of Fish and Wildlife has produced 1-m resolution data for most of western Washington and some of eastern Washington that allow for mapping contemporary and changes in individual trees and tree canopies in cities, suburbs, and rural areas (https://hrcd-wdfw.hub.arcgis.com/pages/canopy).

Further, many cities now have street tree censuses, often for the first time (i.e., New York City, New Haven, Baltimore City, Washington D.C.). Unlike high-resolution tree canopy data, these census data contain lat/long points of individual trees and contain data about tree species, size, and condition. These digital inventories are tied to municipal databases and may have volunteer engagement in collecting the data. For instance, in the 2015–16 New York City street tree census (called "TreesCount!"), over 2000 volunteers walked over 11,000 miles to map over 660,000 trees across over 130,000 blocks; these volunteers completed one-third of the city's census (https://www.nycgovparks.org/trees/treescount). Such repositories are helping produce platforms like OpenTrees which are invaluable public engagement tools and which capitalize on data from over 200 sources and 20 countries currently, although these data are heavily biased to North America, Europe, and Australia (https://opentrees.org) (Figure 6.3).

The push for open data enables anyone to access entire street tree inventories with a few clicks of a mouse, which allows for innovative social and conservation insights. For example, research using Baltimore's freely accessible tree census data found that street trees include 59 unique species that otherwise would not be there (31). However, these data also showed that formerly redlined neighborhoods comprise street trees that have lower species diversity and have fewer old trees (30). Although these data in Baltimore show local organizations are dedicated to ameliorating the distributional injustice, there is still a need for continued effort that diversifies the trees planted,

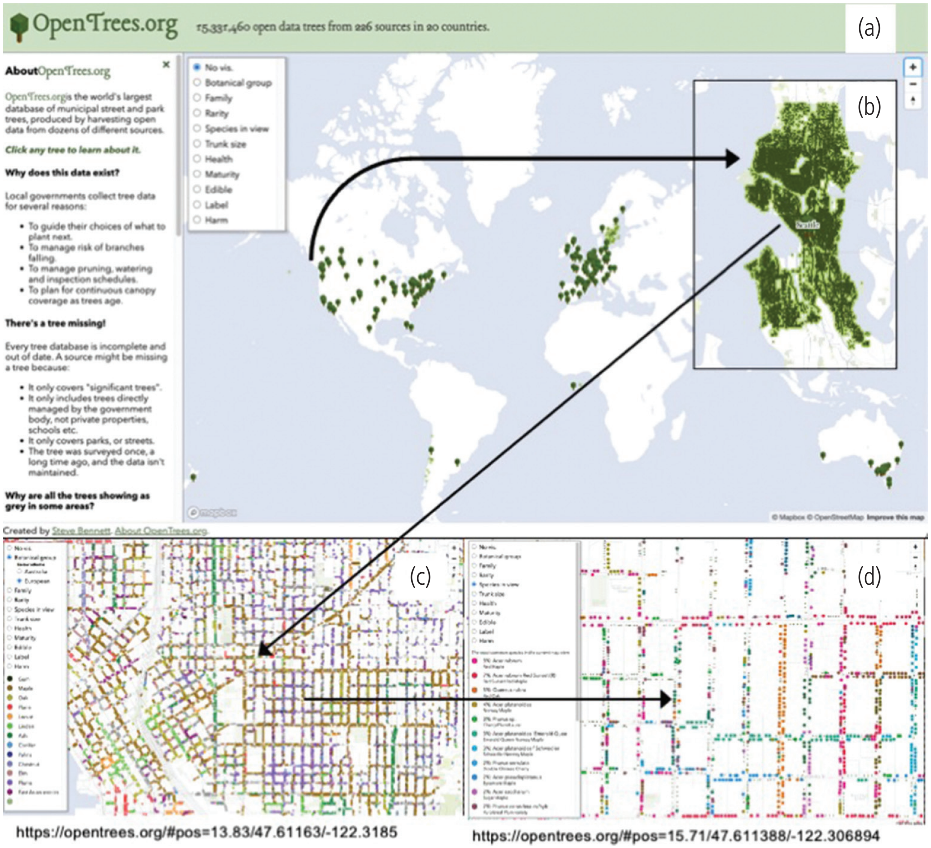

Figure 6.3 Opentrees.org aggregates and serves standardized municipal street tree inventories (a). The map of Seattle, WA (b) can be symbolized by genus (c) and species (d) among other attributes.

both for the biodiversity these urban forests can support but also to enhance the resiliency of the urban forest in marginalized communities against pests and extreme weather, and in other cities, too.

These new tree census and land cover datasets have been used by municipalities for goal setting, monitoring, planning, prioritizing planting, and other purposes (21,67,68). Beyond addressing interesting questions in urban ecology, these mapping innovations have been instrumental in developing our foundational understanding of cities as social-ecological systems, particularly by demonstrating inequities in the distribution and quality of urban tree canopies across wealth and racial boundaries (11–13). Further, if not for urban tree and other vegetation data, studying and managing urban biodiversity more broadly would be substantially more difficult given that trees provide essential habitat conditions for much urban biodiversity.

Urban tree maps facilitate broader urban conservation planning

Urban wildlife biologists can use high-resolution, urban landscape tree and vegetation censuses in at least two helpful ways when designing and analyzing projects. At the design stage, a project area can be divided into different levels of tree canopy and/or impervious surface cover. It is simple and straightforward to obtain the area and percentage of any land cover class (e.g., tree, other vegetation, roads) or combinations of land cover classes within various zones such as parcels, districts, plots, watersheds, or conservation areas. Geographic information system (GIS) software such as ESRI's or free software like QGIS and R can summarize these land cover data easily and are valuable for a multiplicity of urban biodiversity projects including citizen science,[6] for informing sampling plans, or for prioritizing conservation actions. For example, researchers may wish to deploy camera traps in areas of high, medium, or low tree canopy cover. Tree and other land cover summaries can be added in after spatial data are collected or conservation actions are underway. For example, if there is an existing camera trap network, land cover summaries within a range of buffer sizes can be added later. High-resolution tree and land cover data support statistical blocking (e.g., by literal neighborhood blocks with different tree levels) and adding covariates that contextualize habitats.

Case study

In 2006, the Maryland Department of Natural Resources developed the Urban Tree Canopy (UTC) program to encourage cities to conserve and plant new trees to improve the State's waterways and the health of Chesapeake Bay. Baltimore City wanted to participate in the UTC program. Before Baltimore City could establish a goal, however, the City needed to quantify the amount of existing and possible canopy cover for the entire City. For this analysis, the City defined possible canopy cover as areas that were not existing tree canopy cover and were not roads, buildings, or water. The City also needed to know how much of the existing tree canopy was in public ownership, particularly parks and public rights of way in the case of street trees. These questions required detailed, parcel-level analysis. Because of the fine-grain spatial heterogeneity of cities, mid-resolution, remotely sensed data (30 m) were insufficient for this analysis.

Through the Baltimore Ecosystem Study (BES, https://baltimoreecosystemstudy.org/), new methods for combining high-resolution, remotely sensed imagery (>1 m) and LiDAR data were developed to produce highly accurate and visually representative data at the parcel level (69). Visually representative data and parcel-level analysis were two important requirements that decision makers had for the development of these methods. The data product needed to be visually representative at a parcel level in order to convince decision makers and the general public that the data were realistic and therefore legitimate because the data corresponded to how they thought of and perceived their environment. A tree should look like a tree (round, but not too round) and certainly not a pixel (blocky). Summarizing the land cover data within parcels was important because a parcel is the basic unit of decision making and management: parcels are legally binding. The City needed to know how much of the existing and possible urban tree canopy was under its management and how much was associated with other types of ownership or management.

The results from the new land cover map showed canopy cover for the City was 20%, but that the cover varied from 1% to 85% across different neighborhoods. Given the combination of existing and possible canopy cover by neighborhood, some neighborhoods could ultimately have a canopy cover as high as 97% and as low as 29%. In terms of ownership patches, public ownership—street trees and parks—contained only 20% of the existing canopy patches and 14% percent of the possible canopy; while private ownership contained 80% of the existing and 85% of the possible canopy cover. Thus, the City's urban tree canopy goal would be severely limited if it depended only upon conserving existing trees and planting new trees on public lands.

With this information, the City knew the extent of existing and possible canopy cover and its distribution by ownership type and by neighborhood. Yet, the City did not know what the canopy goal should be. Recent watershed research in the region had indicated watershed health declined significantly when existing canopy cover fell below 43% (70). Given that the City's existing canopy cover was 20%, and in consideration of how to "sell" its canopy goal, the City has set a goal of nearly doubling its canopy cover from 20% to 40% by 2036.

Social-ecological applications: who wants urban trees and how to give them away

As described earlier, high-resolution land cover analyses revealed that most land is private residential, most tree canopy cover is private and residential, and most of the opportunities for additional tree canopy are also on private residential land. As well, at the neighborhood level, higher-income and predominantly White areas have more

[6] Perkins et al.'s chapter details how to implement equitable participatory science for urban biodiversity, which often uses GIS tools.

tree canopy cover than their lower-income, communities of color counterparts (11–13). In recognition of these two facts, many municipalities (71) have begun giving free trees away. The rationale is to target residential lands, and by being free, the intention is to reduce the barriers to access in lower-income areas.

Research from Baltimore (72), Washington, D.C. (60), and New York City (73) shows that these well-intentioned programs ultimately end up delivering free or reduced-cost trees to high-income areas with abundant tree canopy on residential land. Put another way, the outreach strategies were extremely effective in reaching one social group, but not others. It is clear that in some areas people do not want trees and/or distrust the government (74,75). In New Haven, CT, the number one reason for requesting a street tree was to replace an old one recently removed (76). In Philadelphia, however, distribution was more even (77), possibly because the City's tree canopy goal was 30% *per neighborhood*. The reasons for participating—or not—vary (71), and this line of research has helped develop best practices for tree distribution programs (78). In some cases, a simple phone call reminder can greatly boost follow-through (79). Each of these programs was young at the time of analysis and has been extremely responsive to these analyses, and the administering groups have changed accordingly. Reanalyses with updated data are needed to evaluate the effectiveness of programmatic changes inspired by these summaries coproduced with urban natural resources managers.

Conclusions and looking forward

In ecology, focus on trees is associated with biomes having sufficient rainfall to support these large, usually water-demanding plants. Urban areas are different from the ecological "addresses" of concern with, study of, and management of trees and forest, however. This is because people in cities and urban places count trees among their important structuring and functional components. Even in typically arid climates and droughty soils, people have often supplied extra moisture or found ways to modify the habitat to support trees. This urban "love affair" with trees means that people have successfully reaped the benefits of arboreal plants in an extraordinary number and variety of cities, suburbs, towns, and villages worldwide, ranging from seacoasts to mountain ranges and tropics to taiga.

The literature and experiences summarized herein yield several insights about trees, some of which point to their relevance to other disciplines within urban sciences, such as wildlife ecology. Other insights show the significant role that trees and urban tree canopy have in setting policy and satisfying goals of sustainability and resilience. We cite eight insights about urban trees and forest.

(1) Urban trees, singly or in stands of several to many trees, are an important contribution to the biodiversity of cities, suburbs, towns, and exurbs. Because people import species not originally present in the native biomes in which cities are located, the tree species richness of the urban forest may be greater than that of surrounding forests and woodlands. Such imported trees may have been chosen for cultural familiarity or significance, or for their ability to thrive in the highly modified environments of cities, including soil compaction and low aeration, soil drought, and atmospheric conditions of pollution, extreme heat, or intense vapor pressure deficits.

(2) All trees in an urban place, regardless of whether planted or tended or not, are part of an urban forest. Of course, an urban forest is usually highly fragmented, with individual specimen trees isolated in yards, parks, and institutional lawns, and with patches of volunteer woods in "waste" lands, vacant lots, or along transportation corridors. Remnant forests of notable extent appear in some cities on old estate or plantation grounds, and new forests are often planted in parks or as amenities in new developments. Finally, of course, street trees, including stately arches of canopy, blocks in length, or widely spaced trees along sidewalks of busy commercial thoroughfares, are also part of the heterogeneous urban forest. Urban forestry, as a research and practical field, is concerned with all of these trees and conditions.

(3) Urban forests perform many services, and this is especially so because they interdigitate with the

spaces where people live, travel, and recreate. Well-being, calming, recreation, nature observation, and interaction with other than human organisms are key benefits that people often experience as individuals. Aggregate benefits emerge from heat mitigation and stormwater control, for example. Notable is that urban forest supports other kinds of biodiversity. Birds, mammals, and insects find shelter, nesting habitat, and food in urban trees. Other plants, ranging from mosses, ferns, epiphytes, and shrubs to spring ephemerals, benefit from the structures and conditions that trees create, either alone or in stands. The interactions between trees and the other plant, animal, and microbial residents in cities, especially those in which evolution may play a part, require additional research. The services differ based on the size and layering of particular parts of the urban forest.

(4) Urban forest and urban forestry are different from "biomic" forestry for another important reason. Understanding and managing the benefits—and hazards—of the urban forest is an integrated social-ecological process. The presence and condition of every tree in a city or town result from human decisions. Where trees are planted, removed, or pruned are all decisions and mean the social and the ecological are inextricably linked in any consideration of the urban forest. Ironically, it is human decisions that lead to neglect and lack of management of urban trees and stands as well.

(5) All forests are complex in their past and spatial relationships, with differences in habitat, herbivores, succession, and disturbance (and more) influencing the distribution, health, and success of individual trees and stands. However, there are additional layers of complexity that must be accounted for in the urban forest. How is the urban forest (including individual trees) apportioned across different parcels? Who manages or makes decisions about each parcel—recognizing that the decision maker may not be the property owner of record. Each parcel will likely have its own history of management of the urban forest, reflecting such things as aesthetic or other values of the occupants, or rules of a homeowners' association, or the life cycle of a family unit as it evolves from raising children to retirement, or a business as it moves from entrepreneurial vigor to a decline in its market. The complexities just outlined can be considered stacked layers that generate virtually unique patterns of heterogeneity that influence urban forests. One particular complication in urban forests is that what may look like a continuous canopy of a single stand may spread over several parcels. Conserving and managing such multi-owner/multi-manager stands requires formal arrangements across ownerships, and may be facilitated by municipal policy that recognizes the social value of contiguous forest canopy for biodiversity and environmental quality.

(6) One implication of the fact that the urban forest is a social-ecological entity, is that people in different social, economic, gendered, or racialized positions may interact with a single urban forest stand or even individual tree in very different ways. It is crucial to understand the variety of perspectives that are in play in a single place or forest. One-size-fits-all policies, or management strategies, or values about urban forest are likely to run afoul of the social diversity of real places where people care about, fear, or ignore trees.

(7) The great social heterogeneity affecting how urban forests are viewed also affects who benefits from them, and who suffers disproportionately from their presence, their condition, or their loss. This highlights the urban forest as a subject of environmental justice. What communities control where trees are located and who allocates resources to their care? What communities are located at convenient distances from large stands in the urban forest, or to tree-shaded sidewalks? What communities can afford the costs or time for pruning, cleaning of leaf litter, and removal of deadfall? What communities have members who participate in professional activities associated with trees, as compared to manual labor? And finally, what are the origins of contemporary patterns of how communities are associated with the urban forest? Much research has documented the role of past activities in determining the location

and composition of the current urban forest. Residential redlining, industrial development, transportation corridors, municipal investment (or lack thereof), power line location and maintenance, and past horticultural fashions are among the many legacies of past decisions and practices that may better explain the contemporary urban forest and how its benefits and burdens are spatially apportioned than contemporary actions. Contemporary actions can, however, restore just urban forest relationships, and can do so with respectful dialog with communities and other stakeholders.

(8) One of the most pervasive themes we discuss here is the productive complexity by which the understanding of the urban forest to date has been produced, and how that understanding is applied to the real world. Understanding the urban forest and ensuring that its benefits are equitably shared, and its burdens likewise are not concentrated on those with less power and fewer resources, combine three activities. The most fundamental component may be improving the data on the urban forest. Remote sensing was a major advance in the discovery of just how pervasive and spatially fragmented the urban forest was. Up until the advent of remote sensing, the term "forest" in urban contexts was associated mainly with large tracts in signature parks, such as the Ramble in New York's Central Park, or even larger stands in its Van Cortlandt or Pelham Bay Parks, Portland's Forest park, or Boston's Emerald Necklace, to name a few. But urbanists also recognized early on in the professional attention of arborists and foresters that the trees along streets were important to the structure, form, and life of cities. Unfortunately, remote sensing of the early generations of satellite technology actually was blind to many of the trees that contributed widely to the urban forest. This was corrected by high-resolution imagery and LiDAR. When these sensors were applied to cities around the world, a much larger urban forest appeared. When those remotely sensed images were combined with LiDAR, trees and canopy could be reliably differentiated within the shadows of tall buildings. Thus, advances in technology were key to understanding that the urban forest was much more extensive, and much more involved with private and small property parcels, than the prior attention to the public rights of way or large public and private institutional grounds suggested.

Theory was a second player in the new discoveries about the urban forest. For example, urban ecologists have shifted from an assumption that cities comprised distinct natural components, such as vegetation and streams, versus distinct socially derived components, such as buildings, infrastructure, and impervious surfaces, to a view that cities are constituted by hybrid social-natural patches. This is a radical reconceptualization of the urban, which interacted with the advances in data.

The third leg of the new urban platform is practice. Whereas ecologists in wild or rural places have, throughout most of the history of their science, largely ignored people, urban ecologists have had to become people-savvy. In wild places it was the assumed absence of contemporary human presence (along with ignorance of long histories of Indigenous presence and management) that permitted dismissal of the human from models and the search for data. Urban ecologists may have in their early days paid relatively scant attention to people as environmental agents, but as the study expanded to more cities, looked in greater historical depth at how the contemporary form and process of cities came about, and became more sensitive to the needs of all communities—not just the powerful economic or racialized elites, a new kind of urban ecology emerged. This sequence can be described as ecology IN the city, ecology OF the city, and ecology WITH the city. Along this continuum, ecologists first stretched their disciplinary boundaries to include other sciences, including the social. And secondly, they began to be sensitive to the diversity of communities, power relations in environmental decision making, and the deep history of inequity and injustice that afflicted cities in the US and indeed elsewhere in the world based on colonialism, slavery, and other extractive labor and resource systems. Environmental justice and environmental racism, areas that emerged first in social movements, have come to be important players in how ecologists understand and work in—and on behalf of—marginalized communities.

These eight insights show the significance of urban forestry understanding, data, and practices as core pillars of understanding urban biodiversity, and improving its benefit and linkages with humans.

References

1. Pataki DE, Alberti M, Cadenasso ML, Felson AJ. The benefits and limits of urban tree planting for environmental and human health. Frontiers in Ecology and Evolution. 2021;9:603757.
2. Ulmer JM, Wolf KL, Backman DR, Tretheway RL, Blain CJ, O'Neil-Dunne JP, et al. Multiple health benefits of urban tree canopy: the mounting evidence for a green prescription. Health and Place. 2016;42: 54–62.
3. Nesbitt L, Hotte N, Barron S, Cowan J, Sheppard SRJ. The social and economic value of cultural ecosystem services provided by urban forests in North America: a review and suggestions for future research. Urban Forestry & Urban Greening. 2017;25:103–11. Available from: https://doi.org/10.1016/j.ufug.2017.05.005
4. Wilson LJ. The Resource Enhancement and Protection Act - one method of meeting our public and resource needs. In: Adams LW, Leedy DL (eds.) Wildlife Conservation in Metropolitan Environments. Columbia, MD: National Institute for Urban Wildlife; 1991. p. 7–14.
5. Wood EM, Esaian S. The importance of street trees to urban avifauna. Ecological Applications. 2020;30(7):e02149.
6. Ossola A, Locke DH, Lin B, Minor ES. Yards increase forest connectivity in urban landscapes. Landscape Ecology. 2019;34(12):2935–48. Available from: https://doi.org/10.1007/s10980-019-00923-7
7. Schell CJ, Dyson K, Fuentes TL, Des Roches S, Harris NC, Miller DS, et al. The ecological and evolutionary consequences of systemic racism in urban environments. Science. 2020;369(6510):eaay4497.
8. Lambert MR, Brans KI, Des Roches S, Donihue CM, Diamond SE. Adaptive evolution in cities: progress and misconceptions. Trends in Ecology and Evolution. 2021;36(3):239–57.
9. Lambert MR, Donihue CM. Urban biodiversity management using evolutionary tools. Nature Ecology & Evolution. 2020;4(7):903–10. Available from: https://doi.org/10.1038/s41559-020-1193-7
10. Roman LA, Pearsall H, Eisenman TS, Conway TM, Fahey RT, Landry S, et al. Human and biophysical legacies shape contemporary urban forests: a literature synthesis. Urban Forestry & Urban Greening. 2018;31:157–68. Available from: http://linkinghub.elsevier.com/retrieve/pii/S1618866717307665
11. Gerrish E, Watkins SL. The relationship between urban forests and income: a meta-analysis. Landscape and Urban Planning. 2017;170:293–308. Available from: https://doi.org/10.1016/j.landurbplan.2017.09.005
12. Schwarz K, Fragkias M, Boone CG, Zhou W, McHale MR, Grove JM, et al. Trees grow on money: urban tree canopy cover and environmental justice. PLoS One. 2015;10(4):e0122051. Available from: https://doi.org/10.1371/journal.pone.0122051
13. Watkins SL, Gerrish E. The relationship between urban forests and race: a meta-analysis. Journal of Environmental Management. 2018;209:152–68. Available from: https://doi.org/10.1016/j.jenvman.2017.12.021
14. Grove JM, Ogden L, Pickett S, Boone CG, Buckley GL, Locke DH, et al. The legacy effect: understanding how segregation and environmental injustice unfold over time in Baltimore. Annals of the American Association of Geographers. 2018;108(2):524–37. Available from: https://doi.org/10.1080/24694452.2017.1365585
15. Nardone A, Rudolph KE, Morello-Frosch R, Casey JA. Redlines and greenspace: the relationship between historical redlining and 2010 greenspace across the United States. Environmental Health Perspectives. 2021;129(1):1–9.
16. Locke DH, Hall B, Grove JM, Pickett STA, Ogden LA, Aoki C, et al. Residential housing segregation and urban tree canopy in 37 US cities. npj Urban Sustainability. 2021; 1(1):15. Available from: https://doi.org/10.1038/s42949-021-00022-0
17. Nowak DJ, Ellis A, Greenfield EJ. The disparity in tree cover and ecosystem service values among redlining classes in the United States. Landscape and Urban Planning. 2022;221:104370. Available from: https://doi.org/10.1016/j.landurbplan.2022.104370
18. Namin S, Xu W, Zhou Y, Beyer K. The legacy of the Home Owners' Loan Corporation and the political ecology of urban trees and air pollution in the United States. Social Science & Medicine. 2020;246:112758.
19. Hoffman JS, Shandas V, Pendleton N. The effects of historical housing policies on resident exposure to intra-urban heat: a study of 108 US urban areas. Climate. 2020;8(1):12. Available from: https://www.mdpi.com/2225-1154/8/1/12
20. Hauer R, Peterson WD. Municipal Tree Care and Management in the United States: a 2014 urban & community forestry census of tree activities [Internet]. University of Wisconsin—Stevens Point;

2016. 78 p. Available from: https://www3.uwsp.edu/cnr/Documents/MTCUS%20-%20Forestry/Municipal%202014%20Final%20Report.pdf

21. Kimball LL, Wiseman PE, Day SD, Munsell JF. Use of urban tree canopy assessments by localities in the Chesapeake Bay watershed. Cities and the Environment. 2014;7(2):9. Available from: http://digitalcommons.lmu.edu/cate/vol7/iss2/9
22. Locke DH, Romolini M, Galvin MF, Strauss EG. Tree canopy change in coastal Los Angeles, 2009–2014. Cities and the Environment. 2017;10(2):3. Available from: http://digitalcommons.lmu.edu/cate/vol10/iss2/3
23. McPherson EG. Monitoring Million Trees LA: tree performance during the early years and future benefits. Journal of Arboriculture and Urban Forestry. 2014;40(5):285–300. Available from: https://www.fs.usda.gov/psw/publications/mcpherson/psw_2014_mcpherson003.pdf
24. Eisenman TS, Flanders T, Harper RW, Hauer RJ, Lieberknecht K. Traits of a bloom: a nationwide survey of U.S. urban tree planting initiatives (TPIs). Urban Forestry & Urban Greening. 2021;61:127006. Available from: https://doi.org/10.1016/j.ufug.2021.127006
25. Doroski DA, Ashton MP, Duguid MC. The future urban forest – a survey of tree planting programs in the Northeastern United States. Urban Forestry & Urban Greening. 2020;55:126816. Available from: https://doi.org/10.1016/j.ufug.2020.126816
26. Yao N, Konijnendijk van den Bosch CC, Yang J, Devisscher T, Wirtz Z, Jia L, et al. Beijing's 50 million new urban trees: strategic governance for large-scale urban afforestation. Urban Forestry & Urban Greening. 2019;44:126392. Available from: https://doi.org/10.1016/j.ufug.2019.126392
27. Berland A, Locke DH, Herrmann DL, Schwarz K. Residential land owner type mediates the connections among vacancy, overgrown vegetation, and equity. Urban Forestry & Urban Greening. 2023;80:127826. Available from: https://doi.org/10.1016/j.ufug.2022.127826
28. Grove JM, Locke DH, O'Neil-Dunne JPM. An ecology of prestige in New York City: examining the relationships among population density, socio-economic status, group identity, and residential canopy cover. Environmental Management. 2014;54(3):402–19. Available from: http://link.springer.com/10.1007/s00267-014-0310-2
29. Coleman AF, Harper RW, Eisenman TS, Warner SH, Wilkinson MA. Street tree structure, function, and value: a review of scholarly research (1997–2020). Forests. 2022;13(11):1779.
30. Burghardt KT, Avolio ML, Locke DH, Morgan GJ, Sonti NF, Swan CM. Current street tree communities reflect race-based housing policy and modern attempts to remedy environmental injustice. Ecology. 2023;104(2):e3881.
31. Anderson EC, Locke DH, Pickett ST, LaDeau SL. Just street trees? Street trees increase local biodiversity and biomass in higher income, denser neighborhoods. Ecosphere. 2023;14(2):e4389.
32. Ponte S, Sonti NF, Phillips TH, Pavao-Zuckerman MA. Transpiration rates of red maple (*Acer rubrum* L.) differ between management contexts in urban forests of Maryland, USA. Scientific Reports. 2021;11(1):22538. Available from: https://doi.org/10.1038/s41598-021-01804-3
33. Phillips TH, Baker ME, Lautar K, Yesilonis I, Pavao-Zuckerman MA. The capacity of urban forest patches to infiltrate stormwater is influenced by soil physical properties and soil moisture. Journal of Environmental Management. 2019;246:11–18. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0301479719307558
34. Pregitzer CC, Charlop-Powers S, Bradford MA. Natural area forests in US cities: opportunities and challenges. Journal of Forestry. 2021;119(2):141–51.
35. Johnson LR, Johnson ML, Aronson MFJ, Campbell LK, Carr ME, Clarke M, et al. Conceptualizing social-ecological drivers of change in urban forest patches. Urban Ecosystems. 2021;24(4):633–48.
36. Doroski DA, Bradford MA, Duguid MC, Hallett RA, Pregitzer CC, Ashton MS. Diverging conditions of current and potential future urban forest patches. Ecosphere. 2022;13(3):e4001.
37. Ossola A, Locke DH, Lin B, Minor E. Greening in style: urban form, architecture and the structure of front and backyard vegetation. Landscape and Urban Planning. 2019;185:141–57. Available from: https://doi.org/10.1016/j.landurbplan.2019.02.014
38. Sonti NF, Campbell LK, Svendsen ES, Johnson ML, Novem Auyeung DS. Fear and fascination: use and perceptions of New York City's forests, wetlands, and landscaped park areas. Urban Forestry & Urban Greening. 2020;49:126601.
39. Sonti NF. Ambivalence in the Woods: Baltimore resident perceptions of local forest patches. Society and Natural Resources; 33(7):823–841. https://www.tandfonline.com/doi/abs/10.1080/08941920.2019.1701162?journalCode=usnr20
40. Perkins DJ. Blind Spots in Citizen Science Data: implications of volunteer bias in eBird data [Master's Thesis]. [Raleigh, NC]: North Carolina State University; 2020. Available from: https://www.proquest.com/docview/2478031545

41. Boone CG, Cadenasso ML, Grove JM, Schwarz K, Buckley GL. Landscape, vegetation characteristics, and group identity in an urban and suburban watershed: why the 60s matter. Urban Ecosystems. 2010;13(3):255–71. Available from: https://link.springer.com/article/10.1007/s11252-009-0118-7
42. Locke DH, Baine G. The good, the bad, and the interested: how historical demographics explain present-day tree canopy, vacant lot and tree request spatial variability in New Haven, CT. Urban Ecosystems. 2014;18(2):391–409. Available from: http://link.springer.com/10.1007/s11252-014-0409-5
43. Grant A, Millward AA, Edge S, Roman LA, Teelucksingh C. Where is environmental justice? A review of US urban forest management plans. Urban Forestry & Urban Greening. 2022;77:127737. Available from: https://doi.org/10.1016/j.ufug.2022.127737
44. Nesbitt L, Meitner MJ, Girling C, Sheppard SRJ, Lu Y. Who has access to urban vegetation? A spatial analysis of distributional green equity in 10 US cities. Landscape and Urban Planning. 2019;181:51–79. Available from: https://doi.org/10.1016/j.landurbplan.2018.08.007
45. Browning MHEM, Rigolon A, Ogletree S, Wang R, Klompmaker JO, Baile C, et al. The PAD-US-AR dataset: measuring accessible and recreational parks in the contiguous United States. Scientific Data. 2022;9(773):1–15.
46. Konijnendijk CC. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: introducing the 3–30–300 rule. Journal of Forestry Research. 2023;34(3):821–30. Available from: https://doi.org/10.1007/s11676-022-01523-z
47. Esperon-Rodriguez M, Tjoelker MG, Lenoir J, Baumgartner JB, Beaumont LJ, Nipperess DA, et al. Climate change increases global risk to urban forests. Nature Climate Change. 2022;12(10):950–5.
48. Esperon-Rodriguez M, Ordoñez C, van Doorn NS, Hirons A, Messier C. Using climate analogues and vulnerability metrics to inform urban tree species selection in a changing climate: the case for Canadian cities. Landscape and Urban Planning. 2022;228:104578.
49. Pallai C, Wesson K. Chesapeake Bay Program Partnership High-Resolution Land Cover Classification accuracy assessment methodology. 2017. Available from: https://www.chesapeakeconservancy.org/wp-content/uploads/2017/01/Chesapeake_Conservancy_Accuracy_Assessment_Methodology.pdf
50. Claggett P, Ahmed L, Buford E, Czawlytko J, MacFaden S, McCabe P, et al. Chesapeake Bay Program's one-meter resolution land use/land cover data: overview and production. 2014. Available from: https://cicwebresources.blob.core.windows.net/docs/LU_Classification_Methods_2017_2018.pdf
51. O'Neil-Dunne JPM, Macfaden SW, Royar A. A versatile, production-oriented approach to high-resolution tree-canopy mapping in urban and suburban landscapes using GEOBIA and data fusion. Remote Sensing. 2014;6(12):12837–65. Available from: http://www.mdpi.com/2072-4292/6/12/12837/
52. O'Neil-Dunne JPM, MacFaden SW, Royar A, Reis M, Dubayah R, Swatantran A. An object-based approach to statewide land cover mapping. In: ASPRS 2014 Annual Conference, Mar 23–28, 2014, Louisville, KY. Available from: https://www.asprs.org/a/publications/proceedings/Louisville2014/ONeilDunne.pdf
53. O'Neil-Dunne JPM, MacFaden SW, Royar AR, Pelletier KC. An object-based system for LiDAR data fusion and feature extraction. Geocarto Interational. 2013;28(3):227–42. Available from: http://www.tandfonline.com/doi/abs/10.1080/10106049.2012.689015
54. MacFaden SW, O'Neil-Dunne JPM, Royar AR, Lu JWT, Rundle AG. High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. Journal of Applied Remote Sensing. 2012;6(1):063567. Available from: https://www.spiedigitallibrary.org/journals/journal-of-applied-remote-sensing/volume-6/issue-1/063567/High-resolution-tree-canopy-mapping-for-New-York-City-using/10.1117/1.JRS.6.063567.short
55. McGee JA III, Day SD, Wynne RH, White MB. Using geospatial tools to assess the urban tree canopy: decision support for local governments. Journal of Forestry. 2012;110:275–86. Available from: https://academic.oup.com/jof/article/110/5/275/4599516
56. Ossola A, Hopton ME. Measuring urban tree loss dynamics across residential landscapes. Science of the Total Environment. 2018;612:940–9. Available from: https://doi.org/10.1016/j.scitotenv.2017.08.103
57. Ossola A, Jenerette GD, McGrath A, Chow W, Hughes L, Leishman MR. Small vegetated patches greatly reduce urban surface temperature during a summer heatwave in Adelaide, Australia. Landscape and Urban Planning. 2021;209:104046.
58. Landry SM, Northrop RJ, Andreu MG, Beck K. City of Tampa urban forest management, monitoring and policy. Florida Geography. 2014;45:44–62.
59. Pu R, Landry SM. A comparative analysis of high spatial resolution IKONOS and WorldView-2 imagery for mapping urban tree species. Remote Sensing of the Environment. 2012;124:516–33. Available from: https://doi.org/10.1016/j.rse.2012.06.011

60. Pham T-T-H, Apparicio P, Séguin A, Landry SM, Gagnon M. Spatial distribution of vegetation in Montreal: an uneven distribution or environmental inequity? Landscape and Urban Planning. 2012;107(3):214–24. Available from: https://doi.org/10.1016/j.landurbplan.2012.06.002
61. Landry S. Connecting Pixels to People: management agents and social-ecological determinants of changes to street tree distributions [Ph.D. Thesis]. [Tampa, FL]: University of South Florida; 2013. Available from: http://scholarcommons.usf.edu/etd/4715/
62. Landry SM, Chakraborty J. Street trees and equity: evaluating the spatial distribution of an urban amenity. Environmental Planning. 2009;41(11):2651–70. Available from: https://journals.sagepub.com/doi/10.1068/a41236
63. Alonzo M, Bookhagen B, Roberts DA. Urban tree species mapping using hyperspectral and lidar data fusion. Remote Sensing of the Environment. 2014;148:70–83. Available from: https://doi.org/10.1016/j.rse.2014.03.018
64. Alonzo M, McFadden JP, Nowak DJ, Roberts DA. Mapping urban forest structure and function using hyperspectral imagery and lidar data. Urban Forestry & Urban Greening. 2016;17:135–47. Available from: https://doi.org/10.1016/j.ufug.2016.04.003
65. Alonzo M, Bookhagen B, McFadden JP, Sun A, Roberts DA. Mapping urban forest leaf area index with airborne lidar using penetration metrics and allometry. Remote Sensing of the Environment. 2015;162:141–53. Available from: https://doi.org/10.1016/j.rse.2015.02.025
66. Alonzo M, Baker ME, Gao Y, Shandas V. Spatial configuration and time of day impact the magnitude of urban tree canopy cooling. Environmental Research Letters. 2021;16(8):84028. Available from: https://doi.org/10.1088/1748-9326/ac12f2
67. Locke DH, Grove JM, Lu JWT, Troy AR, O'Neil-Dunne JPM, Beck BD. Prioritizing preferable locations for increasing urban tree canopy in New York City. Cities and the Environment. 2010;3(1):4. Available from: https://digitalcommons.lmu.edu/cgi/viewcontent.cgi?article=1066&context=cate
68. Locke DH, Grove JM, Galvin MF, O'Neil-Dunne JPM, Murphy C. Applications of urban tree canopy assessment and prioritization tools: supporting collaborative decision making to achieve urban sustainability goals. Cities and the Environment. 2013;6(1):7. Available from: https://digitalcommons.lmu.edu/cate/vol6/iss1/7/
69. Galvin MF, Grove JM, O'Neil-Dunne JPM. A Report on Baltimore City's present and potential urban tree canopy. Annapolis, MD: Maryland Forest Service; 2006. Available from: https://www.fs.usda.gov/nrs/utc/reports/2006_UTC_Report_Baltimore.pdf
70. Goetz SJ, Wright RK, Smith AJ, Zinecker E, Schaub E. IKONOS imagery for resource management: tree cover, impervious surfaces, and riparian buffer analyses in the mid-Atlantic region. Remote Sensing of the Environment. 2003;88(1–2):195–208. Available from: https://www.sciencedirect.com/science/article/abs/pii/S0034425703002414
71. Nguyen VD, Roman LA, Locke DH, Mincey SK, Sanders JR, Fichman ES, et al. Branching out to residential lands: missions and strategies of five tree distribution programs in the U.S. Urban Forestry & Urban Greening. 2017;22:24–35. Available from: https://doi.org/10.1016/j.ufug.2017.01.007
72. Locke DH, Morgan GJ. A market analysis of opt-in tree planting and rain barrel installation in Baltimore, MD, 2008—2012. 2015. Available from: https://dexterlocke.com/wp-content/uploads/2023/05/Locke-Morgan_2015_A-Market-Analysis-of-Opt-In-Tree-Planting-and-Rain-Barrel-Installation-in-Baltimore-MD-2008-%E2%80%94-2012.pdf
73. Locke DH, Mitchell M, Turner C, Douglas J. A market analysis of New York Restoration Project's Tree Giveaway Program, spring 2008—fall 2013. New York Restoration Project; 2014. Available from: http://dexterlocke.com/wp-content/uploads/2023/01/giveawaymarketanalysis_d_locke_m_mitchell_june2014.pdf
74. Carmichael CE, McDonough MH. Community stories: explaining resistance to street tree-planting programs in Detroit, Michigan, USA. Society and Natural Resources. 2019;32(5):588–605. Available from: https://doi.org/10.1080/08941920.2018.1550229
75. Battaglia M, Buckley GL, Galvin M. It's not easy going green: obstacles to tree-planting programs in East Baltimore. Cities and the Environment. 2014;7(2):6. Available from: http://digitalcommons.lmu.edu/cate/vol7/iss2/6/
76. Locke DH, Roman LA, Murphy-Dunning C. Why opt-in to a planting program? Long-term residents value street tree aesthetics. Arboriculture and Urban Forestry. 2015;41(6):324–33. Available from: https://www.fs.usda.gov/nrs/pubs/jrnl/2015/nrs_2015_locke_001.pdf
77. Locke DH, Smith-Fichman E, Blaustein J. A market analysis of TreePhilly's Yard Tree Program, spring 2012—spring 2014. TreePhilly; 2014. Available from: http://dexterlocke.com/wp-content/uploads/2023/01/MarketAnalysis_Report_TreePhillyGiveaways20150120.pdf

78. Roman LA, Nguyen VD, Locke DH, Mincey SK, Sanders JR, Fichman ES, et al. Best practices for yard tree distribution programs. Arborist News. 2017;(Oct);30–5. Available from: https://www.isa-arbor.com/Publications/Arborist-News#archived

79. Hand MS, Roman LA, Locke DH, Fichman ES. Phone-call reminders narrow the intention-action gap by increasing follow-through for a residential tree give-away program. Urban Forestry & Urban Greening. 2019;44:126425. Available from: https://linkinghub.elsevier.com/retrieve/pii/S161886671930247X