

Measuring the 3-30-300 Rule to Help Cities Meet Nature Access Thresholds

Browning, M. H. E. M.^{a*}; Locke, D.H.^{b*}; Konijnendijk, C.^c; S.M. Labib^d; Rigolon, A.^e; Yeager, R.^f; Bardhan, M.^{a,g}; Berland, A.^h; Dadvand, P.^{i,j,k}; Helbich, M.^d; Li, F.^a; Li, H.^l; James, P.^{m,n}; Klompaker, J.^m; Reuben, A.^o; Roman, L.A.^p; Tsai, W-L.^q; Patwary, M.^g; O'Neil-Dunne, J.^f; Ossola, A.^{s,t}; Wang, R.^u; Yang, B.^v; Yi, L.^m; Zhang, J.^w; Nieuwenhuijsen, M.ⁱ

^a Virtual Reality and Nature Lab, Department of Parks, Recreation and Tourism Management, Clemson University, Clemson SC 29631 USA (Matt: 0000-0003-2296-7602; Mondira: 0000-0003-4642-1815, Fu: 0000-0002-9805-0158)

^b USDA Forest Service, Northern Research Station, Baltimore Field Station, Suite 350, 5523 Research Park Drive, Baltimore, MD 21228, USA (0000-0003-2704-972)

^c Nature Based Solutions Institute - Dutch Office, Zeist, The Netherlands (0000-0003-4000-0622)

^d Department of Human Geography and Spatial Planning, Faculty of Geosciences, Utrecht University, Vening Meineszgebouw A, Princetonlaan 8a, 3584 CB, Utrecht, the Netherlands (Labib: 0000-0002-4127-2075; Marco: 0000-0003-0392-8915)

^e Department of City and Metropolitan Planning, The University of Utah, Salt Lake City UT 84112, USA (0000-0001-5197-6394)

^f Division of Environmental Medicine, School of Medicine, University of Louisville, Louisville, KY 40202, USA (0000-0002-5897-1913)

^g Environment and Sustainability Research Initiative, Khulna 9208, Bangladesh (Raju:0000-0001-8895-9723)

^h Department of Geography and Meteorology, Ball State University, Muncie, IN 47306, USA (0000-0003-0473-6405)

ⁱ ISGlobal, Doctor Aiguader 88, 08003 Barcelona, Spain (Payam:0000-0002-2325-1027, Mark: 0000-0001-9461-7981)

^j Universitat Pompeu Fabra (UPF), Doctor Aiguader 88, 08003 Barcelona, Spain

^k CIBER Epidemiología y Salud Pública (CIBERESP), Melchor Fernández Almagro, 3-5, 28029 Madrid, Spain

^l College of Physical Education, Southwest University, Chongqing, China (0000-0002-6147-1362)

^m Harvard T.H. Chan School of Public Health, Boston, Massachusetts, USA. (Yi, L: 0000-0001-6018-0793; Peter: 0000-0002-2858-1973, Jochem: 0000-0002-3260-9692)

ⁿ Harvard Medical School and Harvard Pilgrim Health Care Institute, Boston, Massachusetts

^o Department of Psychology & Neuroscience, Duke University, Durham, NC, 27705, USA (0000-0001-5713-4913)

^p USDA Forest Service, Pacific Southwest Research Station & Northern Research Station, 4995 Canyon Crest Dr., Riverside, CA 92507

^q Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, USA (0000-0002-9183-9025)

^r Spatial Analysis Lab, Rubenstein School of Environment and Natural Resources, University of Vermont, Burlington, VT (0000-0002-5352-7389)

^s Department of Plant Sciences, University of California Davis, Davis, CA, 95616, USA (0000-0002-0507-6026)

^t School of Ecosystem and Forest Science, University of Melbourne, VIC, Australia

^u Centre for Public Health, Queen's University Belfast, Ireland UK (0000-0002-7240-558x)

^v Department of Occupational and Environmental Health, School of Public Health, Sun Yat-Sen University, Guangzhou, 510080, China

^w College of Landscape Architecture, Nanjing Forestry University, Nanjing, China (0000-0003-4696-5652)

*co-corresponding authors: Matthew Browning, mhb2@clemson.edu, Dexter Locke, dexter.locke@usda.gov

Abstract

The 3-30-300 rule offers benchmarks for cities to promote equitable nature access. It dictates that individuals should see three trees from their dwelling, have 30% tree canopy in their neighborhood, and live within 300 meters of a high-quality green space. Implementing this demands thorough measurement, monitoring, and evaluation methods. Seven data and processes exist to assess these components, including vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and green space maps. Our panel of expert's consensus recommends surveys and window-view analyses for the '3', high-resolution land cover maps for the '30', and green space maps with network analyses for the '300'. These methods, responsive to local situations and resources, not only implement the 3-30-300 rule but foster broader dialogue on local desires and requirements. Consequently, these techniques can guide strategic investments in urban greening for health, equity, biodiversity, and climate adaptation.

1. Introduction

The health and well-being benefits of high-quality green space are increasingly recognized¹. These benefits are prominent in the UN Sustainable Development Goal 11 Target 7, which states, "by 2030, providing universal access to safe, inclusive and accessible, green and public spaces, in particular for women and children, older persons and persons with disabilities." Specifically, scholars and practitioners have increasingly focused on urban greening, which involves planting, conserving, and maintaining outdoor vegetation in cities and other urban areas², where increasing numbers of the world's population live. Relatedly, in 2021, Cecil Konijnendijk introduced a new standard for creating healthy, green, equitable cities: the 3-30-300 rule³. 3-30-300 is a set of objective benchmarks for cities seeking to provide their residents with adequate access to nature and the benefits of exposure to natural settings. This approach leverages a vast and growing literature demonstrating the importance of trees and public green spaces, especially close to where people live, work, and play, for mental health, physical health, and climate adaptation⁴⁻⁶.

3–30-300 incorporates three components of nature or “green”: visual green, residential green, and access to green for outdoor recreation. The goal states that everyone should be able to *see* at least 3 well-established trees from their home, workplace, or place of learning; *have* at least 30% tree canopy cover in their neighborhood; and *live* within 300-meters of a high-quality public green space (at least 0.5 ha in size)⁷ (**Fig 1**). This new heuristic for urban nature and green space provision combines different metrics for proximity, quantity, and access. Based on available data and current techniques, we recommend questionnaires and window-view analyses for the 3 component, high-resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component.

The evidence and policy guidelines underpinning the rule are now being fully characterized⁸. In brief, the 30 and 300 components are supported by a significant body of past research findings⁴⁻⁶, and the 300 component aligns with existing recommendations by the European Office of the World Health Organization⁹. There is little evidence yet to support the three components, chosen as a practical aspiration that “rhymes” with 30 and 300, but numerous studies have identified tangible benefits of visual access from homes to greenery for mental health, psychological restoration, and wellbeing¹⁰⁻¹².

Since its launch, the 3-30-300 rule has attracted considerable attention from urban foresters and allied environmental professionals—but also from urban planners and architects, politicians, and journalists. Many cities worldwide, including Malmo, Sweden; Zurich, Switzerland; St Petersburg, Florida; Haarlem, The Netherlands; Saanich, British Columbia; and Viladecans, Spain have already adopted 3-30-300, either formally or informally, as part of their urban forestry or greening programs. International organizations such as the United Nations Economic Commission for Europe¹³ and the Nordic Council of Ministers¹⁴ have recommended implementing 3-30-300. The region of Scania in Southern Sweden has asked consultants to develop an initial assessment method¹⁵. The NGO Future Woodlands Scotland started an urban forestry program with 3-30-300 as the key target¹⁶. Another NGO, Nature Canada, recommends 3-30-300 as part of a strategy to reduce urban forest inequity¹⁷.







3	 <p>Trees visible ≥ 3</p>	 <p>Trees visible < 3</p>
30	 <p>Canopy coverage $\geq 30\%$</p>	 <p>Canopy coverage $< 30\%$</p>
300	 <p>From public GS ≤ 300 m</p>	 <p>From public GS > 300 m</p>
	Met	Not met

Fig 1. 3-30-300 recommends that everyone should be able to *see* at least 3 trees from their residence, workplace, or place of learning; *have* at least 30% tree canopy cover in their neighborhood; and *live* within 300-meters of a high-quality public green space (at least 0.5 ha in size)³.

Epidemiologists have also embraced 3-30-300 as a set of “exposures” worth investigating for potential health and equity benefits. A recent city-wide 3-30-300 study in Barcelona, Spain, reported fewer per capita psychiatrist or psychologist visits in neighborhoods where all three rule components were met¹⁸. Other outcomes were not associated with meeting all three components of 3-30-300, including self-reported mental health and the use of tranquilizers, sedatives, or antidepressants. In a narrower Europe-wide study of the 30% component, it was determined that

reaching 30% urban tree canopy cover could result in a one-third reduction in premature deaths¹⁹.

Despite excitement around the launch and early implementation of 3-30-300, much remains to be clarified about 3-30-300. Various public and private organizations have embarked on developing assessment and monitoring methods to implement the rule^{13,14,15,16,17}. It could be difficult for city administrators and urban planners to know which options are available and recommended when measuring 3–30-300 across urban landscapes.

The objective of this paper is to provide an expert-led and accessible overview of ways to measure the 3–30-300 rule, to promote effective implementation and robust monitoring and evaluation. We begin with the relevant methods, including a definition of terms and data sources, and summarize each metric, including its methodological strengths and weaknesses. We conclude by adapting and extending 3-30-300 by discussing the policy implications of measuring 3-30-300 and geographical and contextual factors that may limit the relevance of using 3-30-300 as a proxy for equitable nature access.

2. Defining terms for 3-30-300

2.1. Tree

Although there is no standard botanical or taxonomic definition of ‘tree’, and varied ways of defining ‘tree’ in urban forestry²⁰, in practical terms, trees are generally considered woody perennial plants whose trunks thicken over time, with some distinctions of tree vs. shrub and other woody herbaceous plants suggesting that trees are taller than 3 meters^{21,22}. Decisions about what qualifies as a tree are often made locally or regionally, for instance, in tropical climates where palms function as trees but do not display the growth patterns of botanically-recognized trees²⁰. Discussions of 3-30-300 generally do not differentiate between tree types but have

recommended mature, well-established, larger trees⁸. This recommendation has been supported by Belgian research finding wider crowns (the upper part of the tree) are associated with fewer mood disorders and cardiovascular medications while higher densities of stems are associated with more of these medications²³. Further evidence is available from a study in Oregon, U.S., documenting older and presumably larger trees showed greater protective associations with lower non-accidental mortality rates than younger trees²⁴. However, there are still numerous benefits associated with small-stature trees, including resident preferences for flowering and fruiting trees²⁵, and cultural affinity for palms (which are not always considered ‘trees’) in some regions²⁶.

2.2. Viewshed

Determining whether a person can view three trees from a window in a building requires an understanding of that person’s viewshed. A viewshed is the landscape visible from a vantage point without obstructions (i.e., buildings or sloped terrain)²⁷. 3-30-300 focuses on viewsheds from any window in homes, offices, and schools. It does not limit viewsheds by location (i.e., bedroom or home office windows).

2.3. Canopy cover

Urban tree canopy cover refers to the proportion of an area (e.g., neighborhood) covered by leaves, branches, and stems of trees when viewed from above. Canopy cover is usually expressed as a percentage, with 0% representing an area with no canopy, and 100% representing an area completely covered by canopy. 3-30-300 does not specify whether 30% canopy cover pertains to summer-time high estimates when deciduous trees are fully leafed. Much research on greenery and human health has utilized single-day estimates, such as maximum values during the summer²⁸. City-wide tree canopy cover goals are common^{25,29}.

2.4. Neighborhoods

Neighborhoods within cities, towns and suburbs are geographically-bound areas of limited size, with relative homogeneity in housing and population, as well as some level of social interaction and symbolic significance to residents^{30,31}. Two types of neighborhood definitions are commonly used in research on greenery and human health: *allocentric* units based on administrative zones (e.g., census tracts) and *egocentric* units based on areas around an individual's location (e.g., their home)^{32,33}. Subjective boundaries can also represent individuals' perceptions of their neighborhood³⁴.

2.5. Urban green space

Urban green space encompasses city areas with greenery that support biodiversity, ecosystem services, or passive and/or active outdoor recreation³⁵⁻⁴⁰. These areas can take on many forms, such as parks, athletic fields, forests, cemeteries, private open spaces, gardens and agricultural areas, green stormwater infrastructure (i.e., rain gardens, bioswales, detention/infiltration basins), and green roofs/walls, among other forms³⁵⁻⁴⁰. 3-30-300 prioritizes definitions that include quality assessments as well as amenities and tangible abilities to affect residents' health and well-being positively. Identification of a high-quality urban green space may depend on place-specific features such as the total canopy and leaf area for heat reduction, recreational facilities such as sport fields and trails for physical activity, and infrastructure such as playgrounds and picnic shelters for social cohesion²⁸.

3. Processing data for measuring 3-30-300

Most data related to measuring 3-30-300 can be organized into seven main categories: vegetation indices, street-level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space property maps (**Fig 2**). The methods of processing these

data can overlap. For example, semantic segmentation - a computer vision technique used to classify and separate objects or regions of an image - can be applied to photographs from windows and street-view images to derive tree visibility. Additionally, some data sources can produce other datasets, such as LiDAR, which is used to derive tree canopy maps. Therefore, these seven categories are discussion points rather than a complete and mutually exclusive set of data sources and processing techniques. The uneven material in these seven categories reflects, in part, the stage development and degree of applicability to 3–30-300.

3.1. Vegetation Indices

Numerous satellite-based products are available to measure vegetation cover. They do not measure tree canopy cover directly. For instance, vegetation continuous field (VCF) values indicate the percentage of vegetative cover ≥ 5 -m in height⁴¹. Moderate Resolution Imaging Spectroradiometer (MODIS) derived VCF data are available annually (2000-present) and globally at a resolution of 250-m². Annual and global VCF data are available from Landsat 5 and 7 imagery at 30-m² resolution at 5-year intervals (2000, 2005, 2010, 2015)⁴². In the U.S., the Multi-Resolution Land Characteristics Consortium provides National Land Cover Database (NLCD) and tree canopy cover estimates at 30-m² resolution^{43,44}. Recently, Lang et al.^{45,46} used Sentinel 2 and Global Ecosystem Dynamics Investigation (GEDI) space-borne LiDAR data to generate 2017-present 10-m² estimates of canopy height, which could be used to calculate canopy cover. NDVI can also be calculated from other satellite, drone, or aerial imagery such as National Agriculture Inventory Program (NAIP) imagery can be used to generate NDVI. NAIP (available in the US only) and LiDAR can be combined to create high-resolution land cover maps see section 3.6). While providing an estimate of vegetation, these above-listed indices do

not provide the percent cover metric for the 3-30-300, or when they do, it is at coarse spatial scales.



Fig 2. Categories of data and processing techniques for 3–30-300

3.2. Street level analyses

Georeferenced street view images (SVI) can be used to calculate several metrics related to 3–30-300⁴⁷. Imagery is available from Google (2007-present), Baidu (2012-present), and Mapillary geotagged photos (2013-present), among other sources. For all three data sources,

individual locations have 360-degree views from images in the four cardinal directions along streets. Images can be used to extract the percentage of greenery along streets. For instance, Harvard University researchers developed a 100-m street network grid for U.S. metropolitan statistical areas by utilizing Google API to find the nearest SVI at each point along a street each year. Computer vision was used to calculate visible greenery (e.g., trees, shrubs, grass, plants, and flowers) through a pyramid scene parsing network (PSPNet)⁴⁸ deep learning model with the ADE20K pre-trained dataset⁴⁸. Similarly, Helbich et al.⁴⁹ used SVI in Amsterdam to create a high-resolution greenness visibility surface, and MIT's Treepedia has performed a similar function for select cities globally⁵⁰. These datasets and image pixel analysis models often cannot count the number of visible trees but instead can create estimates (i.e., SVI with 10% tree cover may represent three visible trees). Other deep learning object detection models like You Only Look Once (YOLO) can also be used to detect and count individual trees in SVIs⁵¹⁻⁵³. Pre-trained deep learning models, such as SegFormer and Mask2Former on CityScapes, are available through open APIs on the Hugging Face platform for tree visibility modeling using SVIs without requiring extensive programming skills. Other image segmentation approaches for SVIs include manual selection in Adobe Photoshop histograms (Adobe, San Jose, CA) and the Brown Dog Green Index⁵⁴. Manual estimates of each tree location, specie, and diameter at breast height (dbh) can be performed on SVI⁵⁵. By design, street-view images focus on streetscapes. So while they may capture street trees (with omission and commission errors), they miss trees in backyards and other spaces entirely⁵⁶.

Street-level analyses can also be performed with light detecting and ranging (LiDAR) products to conduct viewshed analyses that model tree visibility. LiDAR uses laser pulses to measure distances between a sensor and a surface (i.e., the Earth's surface), where the laser beam

is sent toward the ground, and the time it takes for the light to bounce back is measured to determine the distance. Sensors are often located on low-flying aircraft but can be located on unmanned aerial vehicles (UAV) or handheld devices^{57,58}. The resulting high-resolution point cloud data can generate digital surface models (DSMs), three-dimensional representations of the Earth's surface, including natural and anthropogenic features such as trees, buildings, and terrain^{56,59,60}. LiDAR can, therefore, “see through” shadows in urban areas. Several viewshed analysis tools have been developed and applied to model eye-level vegetation visibility, for instance, the GVI-R/Python packages^{56,61}. The open-source GRASS GIS AddOn *v.viewshed.impact* tool can also be applied to model individual tree visibility⁶². By integrating these tools with building and window location information (discussed in Section 3.5), precise representations of tree visibility can be estimated²⁷.

3.3. Tree inventories

Tree inventories are systematic and comprehensive surveys of trees on public lands within a defined area, such as a city. Tree species, size, health, and geolocation are usually available in inventory datasets. Research teams and organizations like OpenTrees.org have compiled datasets across numerous municipalities, such as the Global Urban Tree Inventory⁶³. Some countries have national-scale inventories as well, such as the UK National Tree MapTM. In addition to surveys, photogrammetry can be applied to mobile phone images to create tree inventories⁶⁴⁻⁶⁹. Related to 3-30-300, tree inventories can generate maps that can be compared with residence locations for visibility assessments. Notably, tree inventories are often limited to publicly managed trees (e.g., street trees, public parks) and therefore do not capture private lands, representing a considerable portion of the urban forest in many neighborhoods. Municipal

tree inventories may also be outdated, inconsistently updated, or contain imprecise location data for individual trees.

3.4. Questionnaires

Questionnaires can be administered to residents through the mail, internet, door-to-door interviews, phone calls, text messages, and other methods⁷⁰ to collect data on several aspects of 3–30-300. For example, the Urban National Landowner Survey was developed by the U.S. Forest Service asks respondents about the number of trees on their properties⁷¹. Nieuwenhuijsen et al. assessed window views in Barcelona, Spain, by asking residents whether they could see green elements from their homes¹⁸. These data were cross-referenced with geolocated tree census data. In addition, data on urban green space proximity has been collected by asking residents whether parks are within walking distance or not⁷² as well as the distance to the closest green space⁷³.

3.5. Window-view analyses

Evaluating tree visibility for 3–30-300 requires self-reported, or researcher-assisted, data or geospatial and image analysis methods. In addition to questionnaires (Section 3.1), image segmentation or object detection can be applied to residents' photographs⁷⁴ or trees can be manually counted in these images. Visibility from windows using geospatial (e.g., viewshed) and image analysis methods require three datasets: (1) window location including cardinal direction and exact geolocation, (2) window height including meters above ground level, and (3) terrain information from a digital elevation model or digital surface model, including buildings, trees, and other above-ground features (Section 3.6). Zhang et al.⁷⁵ proposed a green window-view index by extracting the green elements of photos taken by respondents from their most viewed windows with the best viewing angle in the daytime. The best viewing angle is relevant since

wider fields of view may capture more trees than views farther away⁷⁶. This is an experimental method, not yet operational on a city-wide basis. Additionally, using the GVI model and *v.viewshed.impact* tool (Section 3.2) with window location and height information, window-view analyses can be performed using the viewshed approach.

3.6. Land cover maps

Land cover classification is the physical characteristics of the land into categories, such as tree canopy cover, soil, water, or rock. Summarizing a tree canopy class within neighborhood polygons directly can create the “30” metric of the 3-30-300. Recent developments in deep learning models and the availability of Sentinel satellite imagery have allowed the creation of global land cover datasets at 10-m² spatial resolution (**Table 2**). The European Space Agency’s WorldCover map, Esri’s Sentinel-2 Land Cover Explorer, and Dynamic World⁷⁷ provide near real-time data (every 2-5 days) to classify areas with trees or assess green space locations. The Environmental Protection Agency (EPA) provides 1-m² resolution land cover data for select cities currently covering the places where about 70,000,000 people live.

Multiple land cover maps are available specifically for Europe. The Coordination of Information on the Environment (CORINE) Land Cover (CLC) covers all European Economic Area (EEA) countries (1990-present)⁷⁸. The resolution is limited to a Minimum Mapping Unit (MMU) of 25-ha for areal features and minimum width of 100-m for linear features, making it less suitable for intra-city studies. Another Europe-wide land cover map is the Urban Atlas, available for all EEA cities of more than 100,000 inhabitants (2006) or 50,000 inhabitants (2012, 2018)⁷⁹, providing an MMU of 0.25-ha for urban classes and 1-ha for rural classes. The Urban Atlas in Europe since 2012 has included an extra layer for street trees with an MMU of 500-m² and 10-m⁷⁹ (**Table 2**). Additionally, some European countries have higher-resolution LULC

datasets including green space class, such as the Dutch land use model LGN 2020 and UK land use data LCM2015 (**Table 2**).

Table 2. Selected datasets to measure 3-30-300

Measure	Name	Coverage	Further information
<i>Tree locations</i>	OpenTree.org's database of municipal street and park trees	Street trees in selected Cities	https://opentrees.org/
	Global Urban Tree Inventory	Street trees in selected Cities	https://figshare.com/articles/dataset/Global_Urban_Tree_Inventory_GUTI_vers_1_0_/12062634/1
	MIT Senseable City Lab's Treepedia	Street trees in selected Cities	https://senseable.mit.edu/treepedia
	Bluesky International's National Tree Map	United Kingdom	https://bluesky-world.com/ntm/
<i>Canopy cover</i>	ETH Zurich-Barry Callebau's global canopy height from GEDI LIDAR	Global	https://prs.igp.ethz.ch/research/current_projects/automated_large-scale_high_carbon_stock.html
	Google's Environmental Insights Explorer	Selected Cities	https://insights.sustainability.google/?hl=en-US
	Multi-Resolution Land Characteristics Consortium's NLCD tree canopy cover	United States	https://www.mrlc.gov/data/type/tree-canopy
	Local sources	Varies	For example, Chesapeake Conservancy, United States (https://www.chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/lulc-data-project-2022/)
<i>Urban green space</i>	Multi-Resolution Land Characteristics Consortium's National Land Cover Database	United States	https://www.mrlc.gov/
	GlobalLand30	China	http://globallandcover.com/
	Commission for Environmental Cooperation's North American Environmental Atlas	North America	http://www.cec.org/north-american-environmental-atlas/
	European Environment Agency's coordination of information on the environment (CORINE) Land Cover (CLC) inventory	Europe	https://land.copernicus.eu/pan-european/corine-land-cover
	Ordnance Survey (OS) MasterMap Greenspace Layer	United Kingdom	https://beta.ordnancesurvey.co.uk/products/os-mastermap-greenspace-layer
	Land Use Database of the Netherlands (LGN)	The Netherlands	https://www.wur.nl/en/research-results/research-institutes/environmental-research/facilities-tools/kaarten-en-gis-bestanden/land-use-database-of-the-netherlands/different-versions-of-databases/lgn2018-lgn2019-and-lgn2020.htm
	Land Cover Map 2015 (LCM 2015)	UK	https://catalogue.ceh.ac.uk/documents/0255c014-1630-4c2f-bc05-48a6400dd045
	U.S. Environmental Protection Agency (EPA)	United States	https://www.epa.gov/enviroatlas/
	European Environment Agency's Urban Atlas	Selected European Cities	https://land.copernicus.eu/local/urban-atlas
	Esri's Land Cover	Global	https://livingatlas.arcgis.com/landcover/
	PAD-US-AR	United States	https://www.nature.com/articles/s41597-022-01857-7
	Google and The World Resources Institute's Dynamic World	Global	https://dynamicworld.app/
	Latin American cities urban green space map	Selected Latin American cities	https://www.nature.com/articles/s41597-022-01701-y

Digital Surface Models (DSMs) from LiDAR, in conjunction with high-resolution imagery, can then be used to create high-resolution ($\leq 1\text{-m}^2$), high-accuracy ($\geq 95\%$) land cover

maps for measuring the green space locations and canopy cover estimates^{80,81}. For example, the University of Vermont Spatial Analysis Lab has completed approximately 90 land cover and tree canopy change mapping projects^{82–86}. The combination of LiDAR and high-resolution imagery may be considered the gold standard for urban land cover mapping and in service of the 30% canopy cover measure. Other countries have national LiDAR data coverage, such as the AHN in the Netherlands⁸⁷ and Digimap⁸⁸ in the UK. Mobile apps can also leverage some smartphones' LiDAR sensors to create 3D scans of objects and landscapes. Notable examples are KIRI⁸⁹ and ForestScanner⁹⁰. When scaled, these apps may allow communities to create high-resolution 3D maps of trees and vegetation at a lower cost than traditional approaches (i.e., flyovers from low-flying aircraft)⁹¹.

3.7. Urban green space property boundaries

Several national and regional urban green space GIS data are available to identify the locations of urban green spaces such as parks and other open spaces. These GIS datasets are usually stored in a vector data format (e.g., polygons) that are different from generally available grid-based land cover data discussed in the previous section, which does not pertain to land use. Browning et al. recently curated the Parks and Protected Areas Database United States (PAD-US)⁹² to create a PAD-US-AR (PAD-US-[A]ccessible[R]ecreational), specifying parks for public access and outdoor recreation for the U.S.⁹³. Esri's USA Parks contains parks across the U.S.⁹⁴, and the Trust for Public Land's ParkServe contains park locations for nearly 14,000 U.S. cities, towns, and communities⁹⁵. The Urban Atlas in Europe includes a class for urban green space with an MMU of 500-m² and 10-m⁷⁹. The OS MasterMap Greenspace layer in the United Kingdom provides very high resolution green space data including multiple green space types (e.g., parks, gardens, amenity space) (**Table 2**). Outside of Europe and the U.S., Ju et al. created

a map of urban green space in major Latin American cities⁹⁶. We are unaware of similar data Ju et al. for other low to middle income countries (LMICs) and nations. However, some cities in different LMICs countries have their public park data set locally through city authorities, often created as part of the urban master or strategic plans. For example, the city management authorities have detailed green space data in Dhaka⁹⁷ and Johannesburg⁹⁸. Similar data might be available for other cities in different LMICs, but such data might only be accessible through local city authorities.

Globally, urban green space polygons are available from open street map (OSM), which requires a series of user-entered keys (topic/category) and values (features) to map parks and similar areas (i.e., dog parks, playgrounds). The accuracy and consistency of tags vary geographically and are often imprecise, making identifying green spaces difficult⁹⁹. Small, informal open spaces like vacant lots turned gardens are likely missed. Nonetheless, Boeing et al. demonstrated that OSM-based urban green space data could be used in green space accessibility assessments at diverse geographic locations with acceptable accuracy¹⁰⁰.

Spatial proximity analysis can be used with urban green space data to determine the distances to the urban green space maps for 3-30-300. Distances are operationalized based on “as the crow flies” (i.e., Euclidean) or with more sophisticated analyses taking into account transportation networks (e.g., such as streets) and access points (e.g., centroids or entry points for the urban green space)^{33,81,101} (**Fig 3**). Calculating Euclidean distances is simple and fast but can be inappropriate when physical barriers exist, such as roads without pedestrian crossings. Euclidean distances often evaluate whether a green space boundary or access point intersects with the 300-m circular buffer around the home. Necessary data for spatial proximity analysis include home location, green space boundary or access point locations, and road networks^{101,102}.

Urban green space maps often represent polygonal areas¹⁰¹, but for network analysis, the destination must be a point, ideally related to an access location to a green space (e.g., gate). While the polygon's center (centroid, **Fig 3**) can be used as this destination, this approach might lead to overestimated or otherwise inaccurate distances for larger or irregularly-shaped green spaces¹⁰². Some locations have geolocated access points (**Fig 3**), such as the UK Ordnance Survey, and other locations might rely on pseudo-access points created by intersecting the polygon boundary with the road network^{33,101}. Network distances sum the lengths of the street links connecting the origin (home) to the green space. Numerous geospatial software tools such as ArcGIS Pro Network Analyst¹⁰³ and QGIS QNEAT3¹⁰⁴ as well as programming packages (e.g., igraph in C¹⁰⁵; NetworkX¹⁰⁶ and OSMnx¹⁰⁷ in Python; sfnetwork¹⁰⁸ and r5R¹⁰⁹ in R) can run shortest path algorithms such as Dijkstra's or A*¹¹⁰. These tools can connect with road network data and routing engines (e.g., MapBox¹¹¹ and OSRM¹¹²) through APIs, and can adopt different cost functions (e.g., distance, time, and composite cost) to find the shortest distances between origins and the nearest green space. The function of the road network (e.g., for driving, walking, biking, or all three) is relevant in these analyses¹⁰⁷. If walking and biking are the preferred travel modes to green space, highways and other high-traffic roads should be excluded. See Talen¹¹³ and Cardinali et al.⁸¹ for additional guidance on measuring walking access to urban green space.

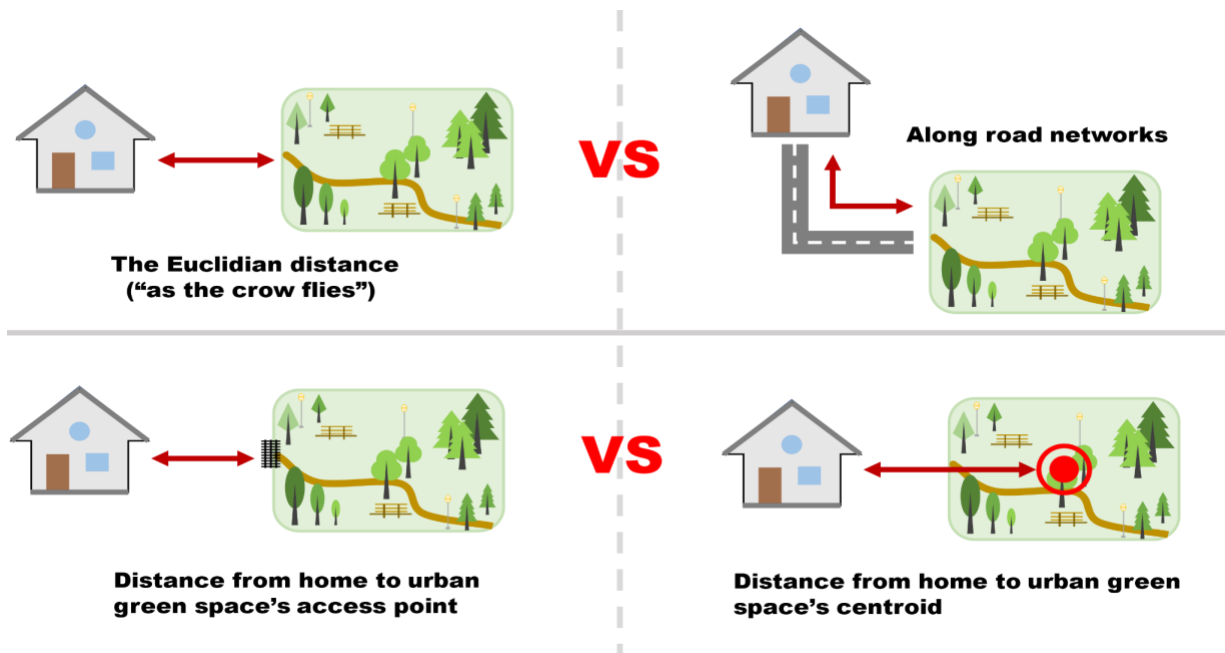


Fig 3. Calculating distance to urban green space is based on transportation mode (Euclidean vs. network) and access point (formal entry vs. centroid distance)

4. Selecting metrics for 3-30-300

Evaluating 3-30-300 can require substantial financial and technical resources. From LiDAR-derived canopy cover to professional assessments of urban green spaces, the necessary resources for highly accurate assessments may be out of reach for some municipalities¹¹⁴. Secondary datasets might be behind paywalls or difficult to process without advanced computing. Such issues are particularly relevant for cities in low and middle-income countries and medium-sized and small municipalities elsewhere. Larger cities in more developed countries, with more staff in planning and park management, might have the capacity and know-how to measure the 3-30-300 rule with the “best” metrics^{115,116}. The relative imbalance of the subsections describing the state of the technologies and measures used to operationalize 3-30-300 is itself a finding. Some measures are harder to describe than others. Not all aspects of 3-30-

300 are well-developed, while others, like high-resolution tree canopy mapping, are well-established industry standards⁸⁰.

Table 1 provides an overview of such metrics as well as our panel of experts’ consensus on the suitability of each metric (i.e., best, fair, or poor). We present the heterogeneity in the quality and availability of data to measure and evaluate 3-30-300. Researchers and practitioners may still be well-served by selecting less-ideal metrics when assessing and monitoring their progress toward meeting the thresholds specified in 3-30-300 then none at all. If data and computational resources are available, questionnaires and window-view analyses are best for assessing the visibility of 3 trees, high-resolution land cover maps are best for measuring tree canopy cover, and urban green space property maps with network analyses are best for the 300 component.

Table 1. Assessment of approaches and datasets (rows) and their suitability for each component of the 3-30-300 rule: see at least 3 well-established trees from their home, workplace, or place of learning; have at least 30% tree canopy cover in their neighborhood; and live within 300-meters of a high-quality public green space (at least 0.5 ha in size)

	Suitability		
	<i>3 trees</i>	<i>30% canopy</i>	<i>300-m distance</i>
Vegetation indices	Poor	Fair	Poor
Street-level analyses	Fair	Poor	Poor
Tree inventories	Fair	Fair	Poor
Questionnaires	Best	Unknown	Fair
Window-view analyses	Best	Poor	Poor
Land cover maps	Fair	Best	Poor
Urban green space property maps	Poor	Poor	Best

5. Adapting and extending 3-30-300

Regardless of how the 3-30-300 rule is measured, each component might have varying degrees of applicability in specific geographic, economic, social, political, and cultural contexts. For example, old European cities, sprawling North American metropolises, new cities in China, and megacities in Latin America and Africa with informal settlements differ in building density,

planning, transportation, zoning, other forms of infrastructure, and governance systems. Select components of the rule may not always be reasonable or warranted, given the opportunity costs of increasing nature access¹¹⁷⁻¹¹⁹. McDonald et al. provided evidence that urbanization and greenery have competing trade-offs, both with benefits for sustainability and human health¹²⁰. Still, numerous greening interventions have been successful at allowing neighborhoods to be both dense and green in diverse settings. For instance, new urban models during the COVID-19 pandemic enabled city streets to serve some of the same functions as urban green spaces, such as superblocks (Barcelona, Spain) and car-free neighborhoods (Freiburg, Germany)¹²¹. Therefore, seeking to meet the components of 3-30-300 may need to be approached with care and creativity. In the section below, we discuss the difficulties and opportunities across geographic contexts for applying and measuring 3-30-300.

5.1. 3 and 30 components

Regarding the 3 and 30 components, many high-density neighborhoods may lack sufficient plantable space. Examples of such places, common to many European cities, eastern US and Canadian cities, and Asian megacities, often have dense apartment buildings, no yard space, and little room for trees outside of public streets or small parks¹²². In such neighborhoods, achieving a smaller threshold of canopy cover (e.g., 15%) could constitute a significant achievement in nature access¹²³.

Climate and climate change might also limit the degree to which the 30 component could be achieved. This threshold might be an unrealistic and unattainable goal in climates with water restrictions^{122,124,125}, such as dry cities in the Middle East, North Africa, the U.S. Southwest, northeastern China, and Australia. For example, the city of Las Vegas (Nevada, U.S.) aims to achieve a 20% canopy cover by 2025, an ambitious goal that would double its most recent

estimate of 10% cover¹²⁶. In cities facing water scarcity outside of forested biomes, concentrating on 30% vegetation cover (rather than tree canopy) may be more appropriate, as well as focusing on native or drought-tolerant plants. Alternative measures to those suggested for 3-30-300 may be appropriate, including a modified soil-adjusted vegetation index (MSAVI)¹²⁷ and fractional vegetation cover (FVC; percent vertical projection of branch, stem and leaves in area)^{128,129}.

Acceptance of new trees might also vary across populations, further hindering a city's capacity to achieve the 3 and 30 components. Some racial/ethnic minority populations in the U.S. have rejected tree planting programs because there was not enough community engagement before planting, and due to legacies of municipal disinvestment, insufficient mature tree maintenance, and associated burdens¹³⁰⁻¹³². Similar barriers have been seen in European cities¹³³. Also, in the U.S., tree planting is often performed by cities or counties, but watering and upkeep are delegated to residents, with some exceptions¹³⁰⁻¹³², creating additional barriers to tree planting and maintenance. In these cases, municipalities may maintain newly planted trees on private lands, facilitate programs for individuals, organizations, or companies to maintain trees along a road segment, or compensate residents for planting and maintaining new trees. In the recently released urban forest plan for Philadelphia (Pennsylvania, U.S.), investing in the maintenance of existing trees (including proactive inspection cycles and removal as appropriate) was framed as crucial to building trust and interest in new plantings (<https://www.phila.gov/documents/urban-forest-strategic-plan/>).

Finally, the 3 and 30 components do not mention quality assessments of the trees (i.e., biodiversity, tree health), nor do they assess management and long-term likelihood of survival of trees that are being planted¹³⁴. Cities implementing 3-30-300 may also improve genus and

species diversity who focusing on native species that are climate-change tolerant for particular areas¹³⁵. For instance, cities could combine 3-30-300 greening efforts with other heuristics such as the 10/20/30 benchmark¹³⁶ suggesting municipal forests diversify with no more than 10% of any one particular species, 20% of any one genus or 30% of any single family; measures like the Shannon Diversity Index (a species diversity calculation)¹³⁷ and Pest Vulnerability Matrix (an urban forest vulnerability calculation); aesthetic evaluations of canopy distributions and shapes¹³⁸.

5.2. 300 component

The feasibility of the 300 component may be dependent on population densities, financing systems for green spaces, and political will to fund urban green space. Low-density cities where the primary transportation mode is the automobile might be unlikely to achieve this threshold. Despite the U.S. goal of everyone living within 10-min walk (800-m) of a park¹³⁹, very few cities (San Francisco, CA being the notable exception) have met this goal¹⁴⁰. Estimates of how many U.S. residents live within a 10-min walk of a park vary between 33% and 75%^{139,141}. Because of relatively low population density and low tax bases in U.S. cities, it might be unattainable to have a park within 300-m of every resident. The same limitation in achieving the 300 component might apply to car-dominated, low-density cities in Canada, Oceania, Europe, and Asia.

The 300 component also does not specify visitation, green space use, or quality. Residents might choose to travel farther from their homes to reach a larger green space or that has the amenities they are looking for (e.g., a sports field) rather than visiting a green space that is within 300-m of their homes. Some studies have shown that park amenities, not proximity, are associated with park visitation¹⁴². Many people in North America choose to drive to parks

instead of walking^{143,144}. Green space visits are associated with better mental and physical health; they may be a better indicator of health benefits than accessibility indicators¹⁴⁵. To this extent, the increasing use of self-report and GPS tracking green space visitation data may need to be cross-referenced with green space accessibility for meaningful measures of the 300 component^{146,152}. Additionally, cities can use participatory processes to define future green space to increase the likelihood of acceptance and use by residents¹⁴⁷⁻¹⁵¹. Since green space visitation may be influenced by pressure and crowding¹⁵², green space cover per capita can be considered a factor in use and subsequent benefits¹⁵³. Relatedly, green space quality may factor into visitation and observed benefits, so professional on-site assessments and delineations through instruments like the 90-item RECITAL survey can refine the extent to delineate the “high-quality” green spaces qualifying for meeting the 300 component^{154,155}.

6. Conclusion

The UN Sustainable Development Goal 11 Target 7 recommends universal access to safe, inclusive and accessible green and public spaces. The 3-30-300 rule provides a set of objective, universal benchmarks for cities to determine how they fare on urban green space proximity, tree canopy coverage, and access, as well as where to target investments for the future. Seven well-defined categories of data and processes to measure 3-30-300 are available, including vegetation indices, street level analyses, tree inventories, questionnaires, window view analyses, land cover maps, and urban green space maps. Based on available data and current techniques, we recommend questionnaires and window-view analyses for the 3 component, high resolution land cover maps for the 30 component, and urban green space property maps with network analyses for the 300 component. These data and processes can inform targeted investments in urban greening for health, equity, biodiversity, climate adaptation, and aesthetics.

Ultimately, such decisions should be responsive to local conditions and available resources, with 3-30-300 representing a starting point for broader discussions about local needs and wants. 3-30-300 can serve as a powerful catalyst for action to address disparities in nature access and improve the health, equity, and well-being of our communities and cities.

7. Acknowledgements

The findings and conclusions in this publication are those of the author(s) and should not be construed to represent any official USDA, U.S. Environmental Protection Agency, or U.S. Government determination or policy. Any mention of trade names, products, or services does not imply an endorsement by the U.S. Government

8. References

1. Zhang, J., Yu, Z., Zhao, B., Sun, R. & Vejre, H. Links between green space and public health: A bibliometric review of global research trends and future prospects from 1901 to 2019. *Environmental Research Letters* **15**, 063001–37 (2020).
2. Eisenman, T. S. *et al.* Urban trees, air quality, and asthma: An interdisciplinary review. *Landscape and Urban Planning* **187**, 47–59 (2019).
3. Bosch, C. K. van den. Promoting health and wellbeing through urban forests – Introducing the 3-30-300 rule. *IUCN* <https://iucnurbanalliance.org/promoting-health-and-wellbeing-through-urban-forests-introducing-the-3-30-300-rule/> (2021).
4. United Nations. SDG Indicators. [https://unstats.un.org/sdgs/metadata/?Text=&Goal=11&Target=.](https://unstats.un.org/sdgs/metadata/?Text=&Goal=11&Target=)
5. Nieuwenhuijsen, M. J. Green infrastructure and health. *Annual Review of Public Health* **42**, annurev-publhealth-090419-102511-12 (2020).
6. Yang, B.-Y. *et al.* Greenspace and human health: An umbrella review. *Innovation* **2**, 100164 (2021).
7. Konijnendijk, C. The 3-30-300 Rule for Urban Forestry and Greener Cities. *Biophilic Cities Journal* **4**, (2022).
8. Konijnendijk, C. C. Evidence-based guidelines for greener, healthier, more resilient neighbourhoods: Introducing the 3–30–300 rule. *J Forestry Res* 1–10 (2022) doi:10.1007/s11676-022-01523-z.
9. World Health Organization Regional Office for Europe. *Urban green spaces: a brief for action*. (2017).

10. Browning, M. H. E. M., Saeidi-Rizi, F., McAnirlin, O., Yoon, H. & Pei, Y. The Role of Methodological Choices in the Effects of Experimental Exposure to Simulated Natural Landscapes on Human Health and Cognitive Performance: A Systematic Review. *Environ Behav* **53**, 687–731 (2020).
11. Patwary, M. M. et al. Exposure to nature during the COVID-19 pandemic and the associated effect on mental health: a systematic review with meta-analysis. *Lancet Planet Heal* **6**, S20 (2022).
12. Labib, S. M., Browning, M. H. E. M., Rigolon, A., Helbich, M. & James, P. Nature's contributions in coping with a pandemic in the 21st century: A narrative review of evidence during COVID-19. *Sci Total Environ* **833**, 155095 (2022).
13. United Nations Economic Commission for Europe. *Sustainable Urban and Peri-urban Forestry*. https://unece.org/sites/default/files/2022-02/Urban%20forest%20policy%20brief_final_0.pdf (2021).
14. Nordic Council of Ministers. *Policy Brief: Unpacking the Green Recovery Spending*. <https://www.norden.org/en/publication/policy-brief-1> (2022).
15. Development Scania. 3-30-300 in Skåne. <https://utveckling.skane.se/publikationer/regional-utveckling/3-30-300-i-skane-analysmodell-for-gronare-och-halsosammare-stader/>.
16. Future Woodlands Scotland. *Invitation to Tender: The Development of a £10m Urban Forestry Fund for Scotland. Introduction: Overview of Future Woodlands Scotland The Urban Forestry Fund*. <https://www.futurewoodlands.org.uk/wp-content/uploads/2022/05/Future-Woodlands-Scotland-Urban-Forestry-Fund-ITT-May-2022.pdf> (2022).
17. Nature Canada. *Canada's Urban Forests: Bringing the Canopy to All September 2022*. <https://naturecanada.ca/wp-content/uploads/2022/09/Nature-Canada-Report-Tree-Equity.pdf> (2022).
18. Nieuwenhuijsen, M. J. et al. The evaluation of the 3-30-300 green space rule and mental health. *Environ Res* 114387 (2022) doi:10.1016/j.envres.2022.114387.
19. Iungman, T. et al. Cooling cities through urban green infrastructure: a health impact assessment of European cities. *Lancet* **401**, 577–589 (2023).
20. Doorn, N. S. van et al. Urban tree monitoring: A field guide. (2020) doi:10.2737/nrs-gtr-194.
21. Richardson, D. M. & Rejmánek, M. Trees and shrubs as invasive alien species – a global review. *Divers Distrib* **17**, 788–809 (2011).
22. Götmark, F., Götmark, E. & Jensen, A. M. Why Be a Shrub? A Basic Model and Hypotheses for the Adaptive Values of a Common Growth Form. *Front Plant Sci* **7**, 1095 (2016).
23. Chi, D. et al. Residential Exposure to Urban Trees and Medication Sales for Mood Disorders and Cardiovascular Disease in Brussels, Belgium: An Ecological Study. *Environ Health Persp* **130**, 057003 (2022).
24. Donovan, G. H. et al. The association between tree planting and mortality: a natural experiment and cost-benefit analysis. *Environ Int* 107609 (2022) doi:10.1016/j.envint.2022.107609.
25. Nguyen, V. D. et al. Branching out to residential lands: Missions and strategies of five tree

- distribution programs in the U.S. *Urban For Urban Gree* **22**, 24–35 (2017).
26. Blair, S. A., Koeser, A. K., Knox, G. W., Roman, L. A. & Thetford, M. Visual health assessments for palms. *Urban For Urban Gree* **41**, 195–200 (2019).
 27. Cimburova, Z. & Blumentrath, S. Viewshed-based modelling of visual exposure to urban greenery – An efficient GIS tool for practical planning applications. *Landscape Urban Plan* **222**, 104395 (2022).
 28. Markevych, I. et al. Exploring pathways linking greenspace to health: Theoretical and methodological guidance. *Environmental Research* **158**, 301–317 (2017).
 29. Locke, D. H., Romolini, M., Galvin, M., O’Neil-Dunne, J. P. M. & Strauss, E. G. Tree Canopy Change in Coastal Los Angeles 2009 - 2014. *Cities and the Environment* **10**, (2017).
 30. Chaskin, R. J. Perspectives on Neighborhood and Community: A Review of the Literature. *Soc Serv Rev* **71**, 521–547 (1997).
 31. Weiss, L., Ompad, D., Galea, S. & Vlahov, D. Defining Neighborhood Boundaries for Urban Health Research. *Am J Prev Med* **32**, S154–S159 (2007).
 32. Chaix, B., Merlo, J., Evans, D., Leal, C. & Havard, S. Neighbourhoods in eco-epidemiologic research: Delimiting personal exposure areas. A response to Riva, Gauvin, Apparicio and Brodeur. *Soc Sci Med* **69**, 1306–1310 (2009).
 33. Labib, S. M., Lindley, S. & Huck, J. J. Spatial dimensions of the influence of urban green-blue spaces on human health: A systematic review. *Environmental Research* **180**, 108869 (2020).
 34. Yang, M., Dijst, M., Faber, J. & Helbich, M. Using structural equation modeling to examine pathways between perceived residential green space and mental health among internal migrants in China. *Environmental Research* 109121 (2020) doi:10.1016/j.envres.2020.109121.
 35. Matsler, A. M., Meerow, S., Mell, I. C. & Pavao-Zuckerman, M. A. A ‘green’ chameleon: Exploring the many disciplinary definitions, goals, and forms of “green infrastructure.” *Landscape Urban Plan* **214**, 104145 (2021).
 36. Jennings, V., Browning, M. H. E. M. & Rigolon, A. *Urban Green Spaces, Public Health and Sustainability in the United States*. (Springer, 2019). doi:10.1007/978-3-030-10469-6.
 37. Taylor, L. & Hochuli, D. F. Defining greenspace: Multiple uses across multiple disciplines. *Landscape and Urban Planning* **158**, 25–28 (2017).
 38. Grabowski, Z. J., McPhearson, T., Matsler, A. M., Groffman, P. & Pickett, S. T. What is green infrastructure? A study of definitions in US city planning. *Front Ecol Environ* **20**, 152–160 (2022).
 39. Li, H. et al. Beyond “bluespace” and “greenspace”: A narrative review of possible health benefits from exposure to other natural landscapes. *Sci Total Environ* **856**, 159292 (2023).
 40. Morpurgo, J., Remme, R. P. & Bodegom, P. M. V. CUGIC: The Consolidated Urban Green Infrastructure Classification for assessing ecosystem services and biodiversity. *Landscape Urban Plan* **234**, 104726 (2023).
 41. Hansen, M. C. et al. Global Percent Tree Cover at a Spatial Resolution of 500 Meters: First Results of the MODIS Vegetation Continuous Fields Algorithm. *Earth Interact* **7**, 1–15 (2003).
 42. Sexton, J. O. et al. Global, 30-m resolution continuous fields of tree cover: Landsat-based

- rescaling of MODIS vegetation continuous fields with lidar-based estimates of error. *International Journal of Digital Earth* **6**, 427–448 (2013).
43. Coulston, J. W. et al. Modeling Percent Tree Canopy Cover: A Pilot Study. *Photogrammetric Eng Remote Sens* **78**, 715–727 (2012).
 44. Nowak, D. J. & Greenfield, E. J. Evaluating The National Land Cover Database Tree Canopy and Impervious Cover Estimates Across the Conterminous United States: A Comparison with Photo-Interpreted Estimates. *Environmental Management* **46**, 378–390 (2010).
 45. Lang, N. et al. Global canopy height regression and uncertainty estimation from GEDI LIDAR waveforms with deep ensembles. *Remote Sens Environ* **268**, 112760 (2022).
 46. Lang, N., Schindler, K. & Wegner, J. D. Country-wide high-resolution vegetation height mapping with Sentinel-2. *Remote Sens Environ* **233**, 111347 (2019).
 47. Biljecki, F. & Ito, K. Street view imagery in urban analytics and GIS: A review. *Landscape Urban Plan* **215**, 104217 (2021).
 48. Zhou, B. et al. Scene Parsing Through ADE20K Dataset. *2017 Ieee Conf Comput Vis Pattern Recognit Cvpr* 5122–5130 (2017) doi:10.1109/cvpr.2017.544.
 49. Helbich, M., Poppe, R., Oberski, D., Emmichoven, M. Z. van & Schram, R. Can't see the wood for the trees? An assessment of street view- and satellite-derived greenness measures in relation to mental health. *Landscape Urban Plan* **214**, 104181 (2021).
 50. Cai, B. Y., Li, X., Seiferling, I. & Ratti, C. Treepedia 2.0: Applying Deep Learning for Large-scale Quantification of Urban Tree Cover. *2018 Ieee Int Congr Big Data Bigdata Congr* 49–56 (2018) doi:10.1109/bigdatacongress.2018.00014.
 51. Redmon, J. & Farhadi, A. YOLOv3: An Incremental Improvement. *Arxiv* (2018) doi:10.48550/arxiv.1804.02767.
 52. Liu, D., Jiang, Y., Wang, R. & Lu, Y. Establishing a citywide street tree inventory with street view images and computer vision techniques. *Comput Environ Urban Syst* **100**, 101924 (2023).
 53. Branson, S. et al. From Google Maps to a fine-grained catalog of street trees. *ISPRS J. Photogramm. Remote Sens.* **135**, 13–30 (2018).
 54. Suppakittpaisarn, P., Lu, Y., Jiang, B. & Slavenas, M. How do computers see landscapes? comparisons of eye-level greenery assessments between computer and human perceptions. *Landscape Urban Plan* **227**, 104547 (2022).
 55. Berland, A. & Lange, D. A. Google Street View shows promise for virtual street tree surveys. *Urban For Urban Gree* **21**, 11–15 (2017).
 56. Labib, S. M., Huck, J. J. & Lindley, S. Modelling and mapping eye-level greenness visibility exposure using multi-source data at high spatial resolutions. *Sci Total Environ* **755**, 143050 (2020).
 57. Tang, L. et al. Assessing the visibility of urban greenery using MLS LiDAR data. *Landscape Urban Plan* **232**, 104662 (2023).
 58. Xia, T., Zhao, B., Xian, Z. & Zhang, J. How to Systematically Evaluate the Greenspace Exposure of Residential Communities? A 3-D Novel Perspective Using UAV Photogrammetry. *Remote Sens-basel* **15**, 1543 (2023).

59. Yu, S. et al. View-based greenery: A three-dimensional assessment of city buildings' green visibility using Floor Green View Index. *Landscape Urban Plan* 152, 13–26 (2016).
60. Vosselman, G. & Maas, H.-G. *Airborne and Terrestrial Laser Scanning*. (Whittles Publishing, 2010).
61. Brinkmann, S. & Labib, S. M. GVI: Greenness Visibility Index R Package. https://zenodo.org/record/7057132#.Y_3c8OzMLmE (2022).
62. Cimburova, Z., Blumentrath, S. & Barton, D. N. Making trees visible: A GIS method and tool for modelling visibility in the valuation of urban trees. *Urban For Urban Gree* 81, 127839 (2023).
63. Ossola, A. et al. The Global Urban Tree Inventory: A database of the diverse tree flora that inhabits the world's cities. *Global Ecology and Biogeography* 13, 169–8 (2020) doi:10.1111/geb.13169.
64. Arboreal AB. Apple App Store: Arboreal-Tree. <https://apps.apple.com/us/app/arboreal-tree/id1444138299> (2018).
65. Marzulli, M. I., Raunonen, P., Greco, R., Persia, M. & Tartarino, P. Estimating tree stem diameters and volume from smartphone photogrammetric point clouds. *For Int J For Res* 93, 411–429 (2020).
66. Vastaranta, M. et al. Evaluation of a Smartphone App for Forest Sample Plot Measurements. *Forests* 6, 1179–1194 (2015).
67. Roberts, J. et al. Mobile Terrestrial Photogrammetry for Street Tree Mapping and Measurements. *Forests* 10, 701 (2019).
68. Texas A&M Forest Service. Trees Count Mobile App. <https://texasforestinfo.tamu.edu/MobileApps/TreesCount/>.
69. The Globe Program. Using Globe Data in your Research. <https://observer.globe.gov/get-data>.
70. Dillman, D. A., Smyth, J. D. & Christian, L. M. *Internet, phone, mail, and mixed-mode surveys*. (John Wiley & Sons, 2014).
71. United States Forest Service. *Family Forest Ownerships of the United States, 2018: Results from the USDA Forest Service, National Woodland Owner Survey*. https://www.fs.usda.gov/nrs/pubs/gtr/gtr_nrs199.pdf (2021).
72. Giles-Corti, B. & Donovan, R. J. Socioeconomic Status Differences in Recreational Physical Activity Levels and Real and Perceived Access to a Supportive Physical Environment. *Prev Med* 35, 601–611 (2002).
73. Helbich, M., Hagenauer, J. & Roberts, H. Relative importance of perceived physical and social neighborhood characteristics for depression: a machine learning approach. *Soc Psych Psych Epid* 55, 599–610 (2020).
74. Lin, T.-Y., Le, A.-V. & Chan, Y.-C. Evaluation of window view preference using quantitative and qualitative factors of window view content. *Build Environ* 213, 108886 (2022).
75. Zhang, J. et al. Is indoor and outdoor greenery associated with fewer depressive symptoms during COVID-19 lockdowns? A mechanistic study in Shanghai, China. *Build Environ* 227, 109799 (2023).

76. Ko, W. H. et al. View access index: The effects of geometric variables of window views on occupants' satisfaction. *Build Environ* 110132 (2023) doi:10.1016/j.buildenv.2023.110132.
77. Brown, C. F. et al. Dynamic World, Near real-time global 10 m land use land cover mapping. *Sci Data* **9**, 251 (2022).
78. European Environment Agency. *Copernicus Land Monitoring Service*. <https://land.copernicus.eu/user-corner/technical-library/clc-product-user-manual> (2021).
79. European Commission. *Mapping Guide v6.3 for a Urban Atlas*. https://land.copernicus.eu/user-corner/technical-library/urban_atlas_2012_2018_mapping_guide_v6.3 (2020).
80. Kimball, L. L., Wiseman, P. E., Day, S. D. & Munsell, J. F. Use of Urban Tree Canopy Assessments by Localities in the Chesapeake Bay Watershed. *Cities and the Environment* **7**, (2014).
81. Cardinali, M., Beenackers, M. A., Timmeren, A. van & Pottgiesser, U. Preferred reporting items in green space health research. Guiding principles for an interdisciplinary field. *Environ Res* 115893 (2023) doi:10.1016/j.envres.2023.115893.
82. O'Neil-Dunne, J. P. M., MacFaden, S. W., Royar, A. R. & Pelletier, K. C. An object-based system for LiDAR data fusion and feature extraction. *Geocarto International* **28**, 227–242 (2012).
83. MacFaden, S. W., O'Neil-Dunne, J. P. M., Royar, A. R., Lu, J. W. T. & Rundle, A. G. High-resolution tree canopy mapping for New York City using LIDAR and object-based image analysis. *Journal of Applied Remote Sensing* **6**, 063567-1-063567–23 (2012).
84. O'Neil-Dunne, J., MacFaden, S. & Royar, A. A Versatile, Production-Oriented Approach to High-Resolution Tree-Canopy Mapping in Urban and Suburban Landscapes Using GEOBIA and Data Fusion. *Remote Sens-basel* **6**, 12837–12865 (2014).
85. O'Neil-Dunne, J. et al. An object-based approach to statewide land cover mapping. in *ASPRS 2014 Annual Conference* (2014).
86. University of Vermont Spatial Analysis Lab. Land Cover Inventory (within the U.S.). <https://uvm.maps.arcgis.com/apps/webappviewer/index.html?id=fe15424caceb4dd294be816581ec2d77>.
87. Actueel Hoogtebestand Nederland. Actueel Hoogtebestand Nederland. <https://www.ahn.nl/>.
88. Digimap. LiDAR. <https://digimap.edina.ac.uk/lidar>.
89. KIRI Innovations. Google Play Store: KIRI Engine - 3D Scanner. <https://play.google.com/store/apps/details?id=com.kiri.kiriengine&pli=1> (2023).
90. Tatsumi, S., Yamaguchi, K. & Furuya, N. ForestScanner: A mobile application for measuring and mapping trees with LiDAR-equipped iPhone and iPad. *Methods Ecol Evol* (2022) doi:10.1111/2041-210x.13900.
91. Pace, R. et al. Tree Measurements in the Urban Environment: Insights from Traditional and Digital Field Instruments to Smartphone Applications. *Arboric Urban For* **48**, 113–123 (2022).
92. U.S. Geological Survey. Protected Areas Database of the United States (PAD-US) 2.1. <https://doi.org/10.5066/P955KPPE> (2020).

93. Browning, M. H. E. M. et al. The PAD-US-AR dataset: Measuring accessible and recreational parks in the contiguous United States. *Sci Data* 9, 773 (2022).
94. Environmental Systems Research Institute. USA Parks. <https://www.arcgis.com/home/item.html?id=578968f975774d3fab79fe56c8c90941> (2022).
95. Trust for Public Land. ParkServe® Data Downloads. <https://www.tpl.org/parkserve/downloads> (2022).
96. Ju, Y., Dronova, I. & Delclòs-Alió, X. A 10 m resolution urban green space map for major Latin American cities from Sentinel-2 remote sensing images and OpenStreetMap. *Sci Data* 9, 586 (2022).
97. Labib, S. M. & Harris, A. The potentials of Sentinel-2 and LandSat-8 data in green infrastructure extraction, using object based image analysis (OBIA) method. *Eur J Remote Sens* **51**, 231–240 (2018).
98. Khanyile, S. & Fatti, C. C. Interrogating park access and equity in Johannesburg, South Africa. *Environ Urbanization* **34**, 10–31 (2022).
99. Ludwig, C., Fendrich, S. & Zipf, A. Regional variations of context-based association rules in OpenStreetMap. *T Gis* **25**, 602–621 (2021).
100. Boeing, G. et al. Using open data and open-source software to develop spatial indicators of urban design and transport features for achieving healthy and sustainable cities. *Lancet Global Heal* **10**, e907–e918 (2022).
101. Wang, S., Wang, M. & Liu, Y. Access to urban parks: Comparing spatial accessibility measures using three GIS-based approaches. *Comput Environ Urban Syst* 90, 101713 (2021).
102. Labib, S. M. Estimating multiple greenspace exposure types and their associations with neighbourhood premature mortality: a socioecological study. *Sci Total Environ* 147919 (2021) doi:10.1016/j.scitotenv.2021.147919.
103. esri. Network Analyst tutorials. <https://pro.arcgis.com/en/pro-app/latest/help/analysis/networks/network-analyst-tutorials.htm>.
104. Raffler, C. QGIS Network Analysis Toolbox 3. <https://root676.github.io/index.html> (2018).
105. igraph core team. igraph - The network analysis package. <https://igraph.org/> (2023).
106. NetworkX Developers. NetworkX: Network analysis in Python. <https://networkx.org/> (2023).
107. Boeing, G. OSMnx: New methods for acquiring, constructing, analyzing, and visualizing complex street networks. *Comput Environ Urban Syst* 65, 126–139 (2017).
108. Meer, L. van der, Abad, L., Bilardi, A. & Lovelace, R. Tidy Geospatial Networks in R. <https://luukvdmeer.github.io/sfnetworks/>.
109. Pereira, R. H. M., Saraiva, M., Herszenhut, D., Braga, C. K. V. & Conway, M. W. r5r: Rapid Realistic Routing on Multimodal Transport Networks with R 5 in R. *Find* (2021) doi:10.32866/001c.21262.
110. Doran, J. E. & Michie, D. Experiments with the Graph Traverser program. *Proc Royal Soc Lond Ser Math Phys Sci* **294**, 235–259 (1966).
111. Walker, K. Penn MUSA Masterclass 2020. [31](http://walker-</div><div data-bbox=)

- data.com/MUSAMasterclass/tutorial/ (2020).
112. Luxen, D. & Vetter, C. Real-time routing with OpenStreetMap data. *Proc 19th Acm Sigspatial Int Conf Adv Geogr Information Syst - Gis '11* 513–516 (2011) doi:10.1145/2093973.2094062.
113. Talen, E. Neighborhoods as Service Providers: A Methodology for Evaluating Pedestrian Access. *Environ Plan B Plan Des* **30**, 181–200 (2001).
114. Hummel, S., Hudak, A. T., Uebler, E. H., Falkowski, M. J. & Megown, K. A. A Comparison of Accuracy and Cost of LiDAR versus Stand Exam Data for Landscape Management on the Malheur National Forest. *Journal of Forestry* (2011).
115. Rigolon, A. & Christensen, J. Examining facilitators and challenges to implementing equitable green space policies: Lessons from Los Angeles County. *Journal of Urban Affairs* (2023) doi:10.1080/07352166.2023.2184695.
116. Lowe, K., Reckhow, S. & Gainsborough, J. F. Capacity and Equity: Federal Funding Competition between and Within Metropolitan Regions. *J Urban Aff* **38**, 25–41 (2016).
117. Rigolon, A., Browning, M. H. E. M., Lee, K. & Shin, S. Access to Urban Green Space in Cities of the Global South: A Systematic Literature Review. *Urban Sci* **2**, 67 (2018).
118. Souza, D. T. de & Torres, P. H. C. Greening and Just Cities: Elements for Fostering a South–North Dialogue Based on a Systematic Literature Review. *Frontiers Sustain Cities* **3**, 669944 (2021).
119. Torres, P. H. C., Irazábal, C. & Jacobi, P. R. Editorial: Urban Greening in the Global South: Green Gentrification and Beyond. *Frontiers Sustain Cities* **4**, 865940 (2022).
120. McDonald, R. I. et al. Denser and greener cities: Green interventions to achieve both urban density and nature. *People Nat* (2022) doi:10.1002/pan3.10423.
121. Nieuwenhuijsen, M. J. New urban models for more sustainable, liveable and healthier cities post covid19; reducing air pollution, noise and heat island effects and increasing green space and physical activity. *Environ Int* 106850 (2021) doi:10.1016/j.envint.2021.106850.
122. Schwab, J. C. *Planning the Urban Forest: Ecology, Economy, and Community Development*. (2009).
123. Pataki, D. E. et al. The Benefits and Limits of Urban Tree Planting for Environmental and Human Health. *Frontiers Ecol Evol* **9**, 603757 (2021).
124. Begert, B. Cities want more trees. Drought is complicating their efforts. *Grist* <https://grist.org/drought/cities-want-more-trees-drought-is-complicating-their-efforts/> (2022).
125. Pincetl, S., Gillespie, T., Pataki, D. E., Saatchi, S. & Saphores, J.-D. Urban tree planting programs, function or fashion? Los Angeles and urban tree planting campaigns. *Geoj* **78**, 475–493 (2013).
126. City of Las Vegas. City of Las Vegas Sustainability Policies and Codes. <https://files.lasvegasnevada.gov/planning/CLV-Sustainability-Policies-and-Codes.pdf>.
127. Qi, J., Chehbouni, A., Huete, A. R., Kerr, Y. H. & Sorooshian, S. A modified soil adjusted vegetation index. *Remote Sens Environ* **48**, 119–126 (1994).
128. Gitelson, A. A., Kaufman, Y. J., Stark, R. & Rundquist, D. Novel algorithms for remote

- estimation of vegetation fraction. *Remote Sens Environ* 80, 76–87 (2002).
129. Purevdorj, T.S., Tateishi, R., Ishiyama, T. & Honda, Y. Relationships between percent vegetation cover and vegetation indices. *Int J Remote Sens* 19, 3519–3535 (1998).
130. Carmichael, C. E. & McDonough, M. H. Community Stories: Explaining Resistance to Street Tree-Planting Programs in Detroit, Michigan, USA. *Soc Natur Resour* 32, 588–605 (2019).
131. Carmichael, C. E. & McDonough, M. H. The trouble with trees? Social and political dynamics of street tree-planting efforts in Detroit, Michigan, USA. *Urban For Urban Gree* 31, 221–229 (2018).
132. Riedman, E. et al. Why Don't People Plant Trees? Uncovering Barriers to Participation in Urban Tree Planting Initiatives. *Urban For Urban Gree* 73, 127597 (2022).
133. Henley, J. “We need trees”: Green vision struggles to take root in Europe’s cities. <https://www.theguardian.com/cities/2023/jan/16/trees-green-vision-europe-cities> (2023).
134. Hilbert, D. R., Roman, L. A., Koeser, A. K., Vogt, J. & Doorn, N. S. van. Urban tree mortality: A literature review. *Arboriculture & Urban Forestry* 5, 167–200 (2019).
135. Which Plant Where. Future proof urban landscape projects with climate-ready species. <https://www.whichplantwhere.com.au/> (2023).
136. Santamour, F. S. Trees for urban planting: diversity, uniformity, and common sense. in *Proceedings of the Seventh Conference of the Metropolitan Tree Improvement Alliance (METRIA)* (1990).
137. Kendal, D., Dobbs, C. & Lohr, V. I. Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? *Urban For Urban Gree* 13, 411–417 (2014).
138. Hu, T. et al. Quantifying the shape of urban street trees and evaluating its influence on their aesthetic functions based mobile lidar data. *Isprs J Photogramm* 184, 203–214 (2022).
139. Trust for Public Land. 10-Minute Walk. <https://10minutewalk.org/> (2023).
140. Land, T. T. for P. ParkScore 2018 Ranking Analysis. https://parkscore.tpl.org/rankings_advanced.php#sm.00013514enxsda0yth1z1uwoadwo (2019).
141. National Recreation and Park Association. *2022 Engagement with Parks Report*. <https://www.nrpa.org/contentassets/257fe28053c6420786927fcffc2f9996/2022engagementreport.pdf> (2022).
142. Kaczynski, A. T. et al. Are park proximity and park features related to park use and park-based physical activity among adults? Variations by multiple socio-demographic characteristics. *Int J Behav Nutr Phy* 11, 146 (2014).
143. National Recreation and Park Association. *2018 American’s Engagement with Parks Report*. (2018).
144. Loukaitou-Sideris, A. & Sideris, A. What Brings Children to the Park? Analysis and Measurement of the Variables Affecting Children’s Use of Parks. *J Am Plann Assoc* 76, 89–107 (2009).
145. Triguero-Mas, M. et al. Living Close to Natural Outdoor Environments in Four European Cities: Adults’ Contact with the Environments and Physical Activity. *Int J Environ Res Pu* 14,

1162 (2017).

146. Triguero-Mas, M. et al. Natural outdoor environments and mental health: Stress as a possible mechanism. *Environmental Research* 159, 629–638 (2017).

147. Rigolon, A. Nonprofits and park equity in Los Angeles: a promising way forward for environmental justice. *Urban Geography* 00, 1–26 (2018).

148. Mattijssen, T., Buijs, A., Elands, B. & Arts, B. The ‘green’ and ‘self’ in green self-governance – a study of 264 green space initiatives by citizens. *J Environ Pol Plan* 20, 96–113 (2018).

149. Loukaitou-Sideris, A. & Mukhija, V. Promotores for Parks? The Potential of a Public Health Model to Improve Outreach and Community Engagement in Park Planning. *Leisure Sci* 45, 281–303 (2023).

150. Mell, I. The impact of austerity on funding green infrastructure: A DPSIR evaluation of the Liverpool Green & Open Space Review (LG&OSR), UK. *Land Use Policy* 91, 104284 (2020).

151. Mattijssen, T., Buijs, A. & Elands, B. The benefits of self-governance for nature conservation: A study on active citizenship in the Netherlands. *J Nat Conserv* 43, 19–26 (2018).

152. Westover, T. N. & Collins, J. R. Perceived crowding in recreation settings: An urban case 2. study. *Leisure Sci* 9, 87–99 (1987).

153. Larson, L. R. et al. Greenspace and park use associated with less emotional distress among college students in the United States during the COVID-19 pandemic. *Environ Res* 204, 112367 (2022).

154. Knobel, P., Dadvand, P. & Maneja-Zaragoza, R. A systematic review of multi-dimensional quality assessment tools for urban green spaces. *Health & Place* 59, 102198 (2019).

155. Knobel, P. et al. Development of the urban green space quality assessment tool (RECITAL). *Urban Forestry & Urban Greening* 126895 (2020)
doi:10.1016/j.ufug.2020.126895.

End June 27, 2023