



# An Urban Forest Diversification Software to Improve Resilience to Global Change

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**Abstract.** The importance of urban tree diversity for improving resilience is increasingly understood by decision makers. Urban foresters want to prevent the overrepresentation of species on their streets and in their city, which could result in a significant loss of canopy cover in the event of a large-scale disturbance such as a drought or an exotic pest or disease. Although numerous software and tools exist to visualize tree inventories and plan tree maintenance work, only a few offer support for increasing tree diversity. After reviewing the existing tools available for urban forest managers, we present SylvCiT, a novel decision-support and open-source software available on a web platform designed to consolidate information related to the urban forest in one place and facilitate decision-making at different scales. While the first interfaces provide the user with a spatially explicit portrait of the urban forest (species richness, functional diversity, structural diversity, i.e., diameter classes) and associated ecosystem benefits (e.g., stored carbon, ornamental value), the software is designed to produce a list of functional groups and appropriate species to plant considering tree species already present. Based on an artificial intelligence algorithm, SylvCiT identifies the types of trees (species and functional groups) that are absent or underrepresented at different scales to make recommendations that increase species and functional diversity to improve resilience to global change. SylvCiT will continue to be developed to evaluate other ecosystem benefits and integrate criteria such as site characteristics into the recommendation algorithm.

**Keywords.** Functional Diversity; Plantation; Software; Urban Forests; Urban Trees.

## INTRODUCTION

To promote ecosystem benefits as well as adaptation to and mitigation of climate changes, more and more trees are being planted in urban areas. Planting programs tend to emphasize either increasing canopy cover (e.g., Boston [29% to 49%], Philadelphia [20% to 30%], and Toronto [27% to 40%]) (Leff 2016) or planting a large number of trees (e.g., Million Tree Initiatives in New York City [MillionTrees NYC 2015], Los Angeles [McPherson et al. 2011], Mississauga [City of Mississauga 2023], London [Million Tree Challenge 2021], Mexico City [Estrategia de Revegetación 2023], and Moscow [Million Trees 2013]) (Sousa-Silva et al. 2023). Tree planting initiatives should not focus only on quantity but also on diversity, because urban forests are generally dominated by a few species or genera (Paquette et al. 2021), and changes in tree species and genera have been relatively minor over the last 40 years (Ma et al.

2020). A study of more than 100 cities around the world has shown that urban forests have on average 20% trees of the same species, 26% of the same genus, and 32% of the same family, which does not respect the well-known 10-20-30 ‘rule of thumb’ (Kendal et al. 2014). According to this guideline, each species should not represent more than 10% of the inventory, each genus must not represent more than 20% of the inventory, and each family must not represent more than 30% of the inventory (Santamour 1990). Across the United States, 61.5% of the street trees are represented by only 6 species, and the most abundant species in any community account for, on average, 23.7% of all trees (Ma et al. 2020). Although many cities may be species rich, they often have low diversity due to the dominance of a few species (Paquette et al. 2021). *Acer* is the most common genus of street trees in the Northeastern USA (Cowett and Bassuk 2017), while in many Nordic European

cities, the genus *Tilia* is the most dominant (Sjöman et al. 2012).

Urbanization decreases both species evenness (Shannon's diversity index, accounting for species abundance) and functional diversity (Nock et al. 2013). Functional diversity is the diversity of biological characteristics (functional traits) within a community, including any measurable feature at the individual level affecting its fitness and survival, such as seed size, specific leaf area, and leaf nitrogen content (Violle et al. 2007). These traits influence how trees respond and adapt to environmental factors (Garnier and Navas 2012).

Tree species with similar traits can be clustered into functional groups such as pioneer species, late-successional species, and large-seeded species (Paquette et al. 2021). Paquette et al. (2021) suggested that planting species from different functional groups improves functional diversity and thus increases urban forest resilience, because tree species with different traits will have different responses to threats. Urban forests face and will continue to face unexpected stressors associated with global change (e.g., climate change, novel pests or pathogens), such as the increasing frequency of drought events, the extension of urban heat islands, and the invasion of emerald ash borer, Dutch elm disease, and horse chestnut leafminer, which may lead to large losses of trees and their associated benefits (Raupp et al. 2006; Ordóñez and Duinker 2015; Lovett et al. 2016; Hudgins et al. 2022; Stemmelen et al. 2022). The particular problem encountered by city managers is the high uncertainty about what extreme weather events (e.g., wind storms, heat stress, ice), exotic insects, or diseases will hit next (Foran et al. 2015), reinforcing the importance of increasing diversity to be better prepared for any eventuality.

Because of the importance in promoting urban forest resilience, managers need tools to help them improve diversity, which is the goal of SylvCiT. SylvCiT is, to the best of our knowledge, the only open-source software that helps managers plan for functional diversity of trees in urban settings. Because existing urban forestry tools do not consider functional trait diversity, do not allow for multi-scale analysis, or can be technically prohibitive to urban forest managers (i.e., required programming), we developed SylvCiT to generate better tree planting recommendations that improve urban forest resilience by

including features that overcome these shortcomings. The main objectives of this paper are (1) to present the existing tools and software available to urban decision makers, (2) to compare them with SylvCiT, and (3) to highlight the functions and uniqueness of SylvCiT with a description of the tool, an example of its use, and details on future development.

We carried out a non-exhaustive search for urban forestry software, tools, and web applications available on the world-wide-web. We then based our review on the assessment of 12 urban tree monitoring software packages conducted by Boyer et al. (2016). We also searched for peer-reviewed and gray (not published in academic journals) literature from different scientific databases and search engines such as *Sofia* and *Google Scholar* using a combination of these keywords: 'urban tree', 'urban forest', 'urban canopy', 'ecosystem services', 'software', 'tool', 'application', 'decision-making tool', and 'decision-support tool'. We identified the main differences between SylvCiT and these other software and tools.

## COMPARISON OF EXISTING TOOLS

A plethora of urban forestry tools and software are available to urban forest stakeholders and managers for different purposes (Table 1). Many of them are used for urban tree monitoring such as *TreeKeeper Inventory Management Software* (Davey Tree Expert Company), *TreePlotter* (PlanIT Geo), *Urban Forest Metrix* (Forest Metrix Pro), *ArborPro* (ArborPro Inc.), and *ArborScope* (Bartlett Tree Experts). They were developed to facilitate tree inventories, mapping, and management. These tools are useful for monitoring tree growth, condition, and mortality, and the evolution of the urban forest in terms of structural and species diversities (Boyer et al. 2016). Unlike SylvCiT, which is an open-source and free-to-use software, most of these software are commercial, although some have free or low-cost options.

Data collection software platforms like *Collector for ArcGIS* (Esri) and *AppSheet* are often used by urban forest managers (Boyer et al. 2016) while non-profit organizations, citizens, and some private firms prefer to use free and open-source tools such as *QField* (QGIS) and *Kobo Toolbox*. SylvCiT does not collect field data but instead uses georeferenced public tree inventories made available by cities. Other software such as *Arbogold*, *ArborNote*, *SingleOps*, and *Treezi* are mostly used by tree care providers,

**Table 1. Presentation of different urban forest software, applications, and tools. N/A = not applicable.**

Type of tool	Name of tool	Company/institution	Country/region	Free to use?	Publication
Planting-recommendation, species-selection, decision-making tools	Citree	Technische Universität Dresden	Central Europe	Yes	Vogt et al. 2017
	i-Tree Species	USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, SUNY College of Environmental Science and Forestry	Worldwide	Yes	Nowak et al. 2018
	Right Place Right Tree—Boston	Boston University Biogeoscience and URBAN graduate programs	Boston, USA	Yes	Werbin et al. 2020
	Select Tree	Urban Forest Ecosystems Institute, California Polytechnic State University	California, USA	Yes	N/A
	SESAME	Cerema, Ville de Metz et Metz Métropole	France	Yes	Cerema 2019
	Tree Advisor	USDA National Agroforestry Center	Northern and Central Great Plains, USA	Yes	Bentrup and Dosskey 2022
	Tree Planting Predictor™ Tool	Edge Impact	Worldwide	Partially	N/A
	Which Plant Where	Macquarie University	Australia	Yes	Ellsworth et al. 2018
Urban ecosystem services assessment <sup>a</sup>	EcoServR	Liverpool John Moores University, Natural Capital Solutions, Forest Research, and the Cheshire Wildlife Trust	United Kingdom	Yes	Busdieker et al. 2020
	i-Tree Eco, i-Tree Design, MyTree	USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, SUNY College of Environmental Science and Forestry	Worldwide	Yes	Hirabayashi et al. 2022
	OpenTreeMap	AZAVEA, Inc.	North America	No	N/A
	Social Values for Ecosystem Services (SolVES)	United States Geological Survey	Worldwide	Yes	Sherrouse et al. 2022
	Urban InVEST	Natural Capital Project	Worldwide	Yes	Hamel et al. 2021
Microclimate simulation models	ENVI-met	ENVI-met GmbH		No	Tsoka et al. 2018
	Greenpass	GREENPASS GmbH	Worldwide	No	Elagiry et al. 2019; Kraus and Scharf 2019
	Computational fluid dynamics software	e.g. SimScale, OpenFoam	Worldwide	Yes/No	Buccolieri et al. 2018

Table 1 continued on next page

Table 1. Continued.

Type of Tool	Name of Tool	Company/institution	Country/region	Free to use?	Publication
Tree explorer, canopy explorer, citizen science, visualisation tools	Exploring Tree Equity in Boston	Speak for the Trees, Boston	Boston, USA	Yes	N/A
	Falling Fruit	Falling Fruit	Worldwide	Yes	N/A
	Google Earth Engine Apps	Tree Canopy Lab (e.g., Los Angeles)	USA	Yes	N/A
	Healthy Trees, Healthy Cities	The Nature Conservancy, USDA Forest Service, and the Center for Invasive Species and Ecosystem Health at the University of Georgia	Worldwide	Yes	Hallett et al. 2019
	i-Tree Canopy, i-Tree Landscape, OurTrees	USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, International Society of Arboriculture, Casey Trees, SUNY College of Environmental Science and Forestry	Worldwide	Yes	Nowak et al. 2018
	New York City Street Tree Map	City of New York, New York City Parks	New York, USA	Yes	N/A
	Many other cities with similar platforms	e.g., Seattle, San Francisco, Los Angeles (USA); Montréal, Québec, Ottawa (Canada)	Worldwide	Yes	N/A
	MapMyTree	European Environment Agency	Europe	Yes	N/A
	OpenTrees.org	Steve Bennett, freelance web developer	Worldwide	Yes	N/A
	Tree Equity Score Analyser	American Forests	USA	Yes	N/A
	Treepedia	MIT Senseable City Lab, World Economic Forum	Worldwide	Yes	Abbati 2019; Cai et al. 2018
Tree inventory, data collection, mapping, tree management	TreeKeeper Canopy	Davey Tree Expert Company	Worldwide	No	N/A
	ArborPro	ArborPro, Inc.	USA	No	N/A
	ArborScope™	Bartlett Tree Experts	North America, Europe	No	N/A
	ArcGIS Collector	Esri	Worldwide	No	N/A
	TreeKeeper Inventory management software	Davey Tree Expert Company	North America	No	N/A
	TreePlotter	PlanIT GEO™	Worldwide	No	Morar et al. 2019
Tree care, software for arborists <sup>b</sup>	Urban Forest Metrix	Forest Metrix Pro	USA	No	N/A
	Arborgold	Arborgold	Worldwide	No	N/A
	Arbornote	Arbornote	Worldwide	No	N/A
	SingleOps	SingleOps	Worldwide	No	N/A
	Treezi	A Plus Tree, Inc.	Worldwide	No	N/A

<sup>a</sup> For a more detailed review of ecosystem services assessment tools, see Bagstad et al. 2013.<sup>b</sup> For more information on these tools, consult Boyer et al. 2016.

arborists, and landscaping companies to plan and monitor arboricultural work.

The model *i-Tree* has been the most frequently used to describe the characteristics and structure of urban forests, particularly the ecosystem benefits they provide, and *i-Tree Eco* has been the most implemented tool because it is free, does not require programming, and is available for many locations (Lin et al. 2019; Hirabayashi et al. 2022). Tools from the *i-Tree* suite can be classified into three categories (i-Tree 2022):

- tools to assess tree canopy area (e.g., *i-Tree Canopy*);
- web tools for tree planting, i.e., *i-Tree Species*, which gives recommendations for the most appropriate species based on ecosystem services and geographic area; and,
- tools for assessing individual trees, i.e., *i-Tree Eco* (formerly *UFORE*), which quantifies the structure, threats, benefits, and values (biophysical and monetary) provided by urban trees.

While the tools from the *i-Tree* suite available through a web browser are simple and intended for a wide audience, not all of their tools are easy to use or spatially explicit, and none are open source like SylvCiT.

Despite the widespread use of *i-Tree*, there is an influx of new ecosystem benefit assessment tools. *EcoservR* uses spatial models to map the capacity of habitats to provide ecosystem services and estimate the demand for them (Busdieker et al. 2020). *Urban Invest* (Natural Capital Project 2022) software includes a model of urban cooling and urban flood risk mitigation based on tree canopy (Hamel et al. 2021). The web-based tool *NBenefit\$*, soon to be incorporated into the *Nature4Cities Platform*, analyzes the costs and benefits of different scenarios and nature-based solutions implemented in urban environments (Nature4Cities 2020). *Social Values for Ecosystem Services (SolVES)* is an open-source GIS application created to map and quantify the social values of ecosystem services (Sherrouse et al. 2022). As described later in this manuscript, SylvCiT estimates carbon storage and ornamental value.

Microclimate simulation models like *Envi-met* and CFD models are based on fluid dynamics. *Envi-met* simulates and analyzes the interactions between vegetation (e.g., trees) and microclimate (Tsoka et al.

2018). CFD quantifies the thermal effects of trees on surrounding buildings (Buccolieri et al. 2018). These models require new parameters related to the study site when applied outside their original modeling domains, unlike *i-Tree*, which can be used in many locations. One of the limitations of CFD software is the need for the user to have programming knowledge (Lin et al. 2019). These tools are mostly used by academics and not managers due to their complexity and difficulty to parameterize. SylvCiT does not simulate microclimate, but it shows the urban heat islands (INSPQ and CERFO 2012) that will soon be linked to the recommendation algorithm to suggest appropriate species for these warm and dry environments.

Many cities and organizations have developed or used web applications to educate, sensitize, and inform citizens and stakeholders on the importance of trees and the urban canopy. For instance, *Treepedia* uses computer vision techniques to increase the awareness of urban vegetation improvement (Cai et al. 2018). The goal of tree explorers like *New York City Street Tree Map* (NYC Parks) is to educate people about the trees in their local environments. Others, like *Exploring Tree Equity in Boston* (Speak for the Trees, Boston) or *Tree Equity Score Analyzer* (American Forests) focus on the social aspects and inequities of the urban forest. Because it is easy to use, SylvCiT may also serve as a tree explorer and as a tool to sensitize and educate.

Urban forest managers that want tree species recommendations based on species characteristics (e.g., maximum tree height, light requirement, moisture tolerance), tree appearance (e.g., blossom color, autumn coloring), site characteristics (e.g., hardiness zone, available planting area), potential environmental services (e.g., carbon storage, streamflow reduction), and/or climate change adaptation can turn to the many web databases and applications such as *Citree* (Vogt et al. 2017), *Woody Plants Database* (Cornell University 2023), *Select Tree* (UFEI 2023), *i-Tree Species* (i-Tree 2022), *Right Place, Right Tree, Boston* (Werbin et al. 2020), and *SESAME* (Cerema 2019). The multidisciplinary team of the *Which Plant Where* project at Western Sydney University and Macquarie University is building a plant selection tool that aims to recommend heat and drought tolerant species that will survive in future Australian urban climates (Ellsworth et al. 2018). However, SylvCiT is the only

software that recommends groups and species to increase tree diversity of an area selected by a user.

## GENERAL DESCRIPTION OF SYLVCiT

SylvCiT is a decision-support tool that integrates methods from urban forestry, functional ecology, and computer science. Our open-source software and its web platform use Mapbox MBTiles servers (Mapbox 2023) to store spatial data (Figure 1). These data are generated by combining tree inventories and available maps from OpenStreetMap (OpenStreetMap 2022), a project aimed at creating a free, collaborative geographic database for the globe. SylvCiT represents tree data over different map types, such as a street map, a map with satellite imagery, and a map that identifies urban heat islands (in orange and red) and cool areas (in green)(INSPQ and CERFO 2012).

The tool is configured using a simple georeferenced tree inventory (e.g., species name, diameter at breast height [DBH], tree condition, planting date, inventory date) and information databases (e.g., functional groups database)(Figure 1). It can be used like a tree explorer by different stakeholders interested in learning about trees in their environment. To get information on a specific tree, users can click on a colored circle (the size of the symbol is correlated to tree size, as measured by DBH, and the color is associated with a tree species)(Figure 2A). Users can define an area of interest to know more about the urban forest characteristics of a park, a street, a neighborhood, or a whole city (Figure 2B). SylvCiT can also be used by stakeholders aiming to improve tree diversity at their scale of interest by choosing appropriate species to plant in their urban area. The databases integrated

### Databases (SQL, Apache, Solr)

- Species names and Functional groups
- Maximum DBH per species
- Tree biomass data
- Ornamental value data (e.g., tree cost)
- Recommended species

### Spatial information (MapBox, OpenStreetMap)

- Street map
- Satellite image
- Urban heat islands

### Urban tree inventory

(Data cleaning and map projection using Python)

Tree  
explorer

#### Home interface

- Number of urban trees and unique species in the view
- Proportion of trees per species
- Information on a selected tree (e.g., species name, DBH, date of inventory, date of plantation)

Urban forest  
analysis

#### Selecting an area

- Number of urban trees, of old trees, and of trees/ha
- Proportion of trees per functional group (funct. group richness and diversity)
- Proportion of trees according to the 10-20-30 rule
- Proportion of trees per species (species richness, species diversity)
- Proportion of trees per DBH classes and number of old trees per functional group
- Ornamental value
- Carbon storage and social cost of carbon

Tree  
recommendations

#### Simulating a plantation

- Always improving functional group diversity
- Improving other features on demand (e.g., species diversity, carbon storage)
- Recommended functional groups and species to plant
- Urban forest analysis after the simulated plantation

**Figure 1.** SylvCiT is a decision-support tool for recommending appropriate groups of tree species to plant in a city to improve functional diversity at different scales. This open-source software integrated into a web platform can also be used as a tree explorer or as a tool to analyze the diversity of the urban forest at different scales and find information on ecosystem benefits.

in the system allow SylvCiT to be used in cities in northeastern North America. SylvCiT is available in English and in French at <https://sylvcit.ca>. The open-source code is publicly available at <https://gitlab.com/ikb-lab/ikb-lab1/data-science/sylvcit> under a GPL-v3 license.

### THE ANALYSIS OF THE URBAN FOREST

SylvCiT characterizes the urban forest at different scales. After defining an area of interest (Figure 2B), the user is directed to the module describing the current status of the trees within the defined area (in our

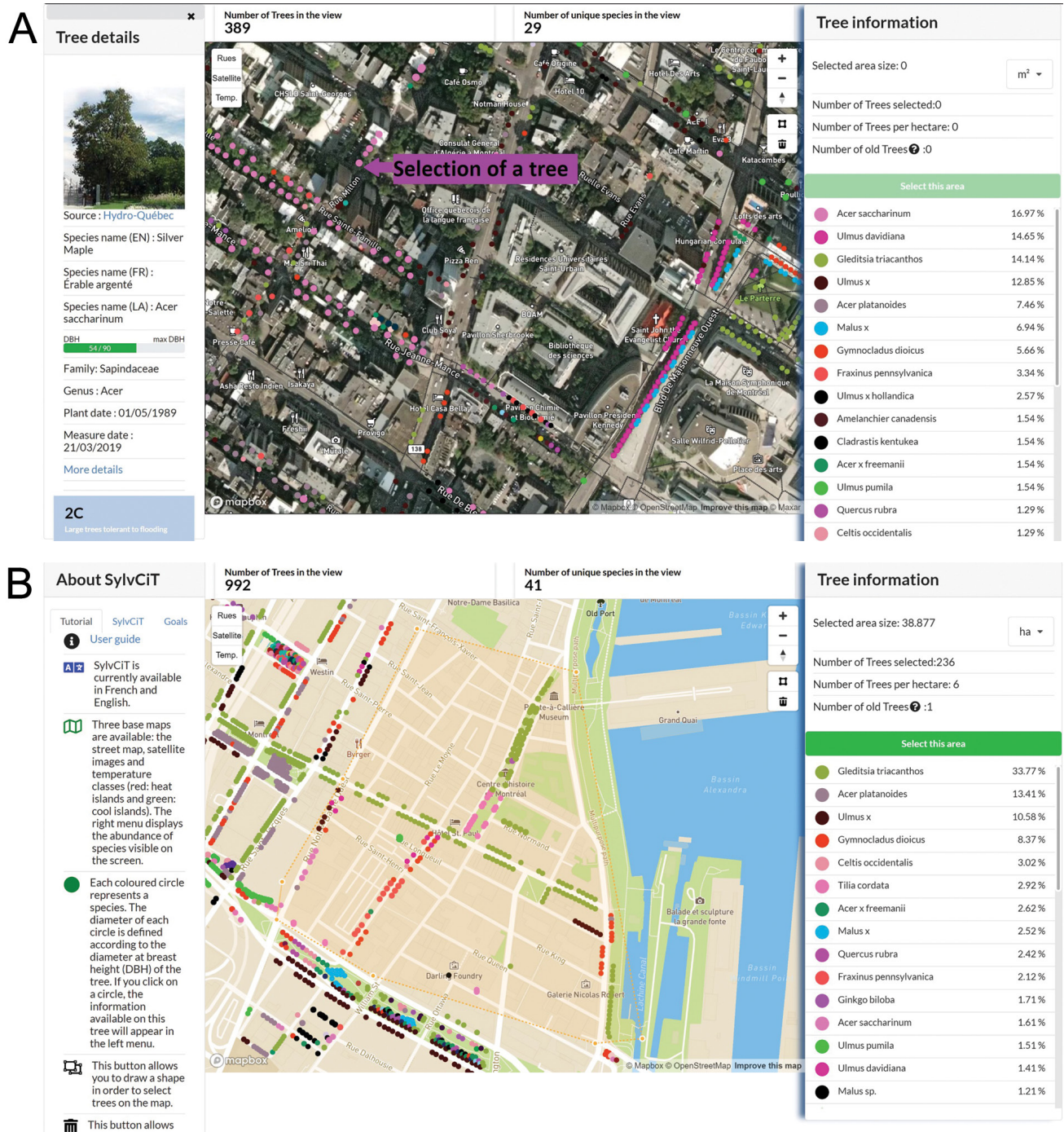


Figure 2. SylvCiT can be used as a tree explorer to retrieve information about individual trees (A) or about the urban forest within a selected area (B). This example shows an area near the Old Port of Montreal, Canada.

example, 236 trees were selected). The first attributes are related to functional groups (Paquette 2016). The functional group richness (i.e., the number of functional groups in the selected area) and the functional group diversity (which accounts for the relative abundance of functional groups) are presented as well as the number of trees in each functional group. The species richness and effective number of species (species diversity) are presented in the same way, and a graph of the frequency of the 10 most abundant species is shown.

SylvCiT also gives information on the distribution of trees according to the 10-20-30 rule, indicating the proportion of species, genera, and families of trees. This rule has no scientific base, but it has been widely used by urban forest managers. SylvCiT provides information on forest structure by showing the distribution of DBH classes and the number of old trees by functional group. Tree size may be used as a proxy to identify old trees (Sousa-Silva et al. 2021). We used a combination of 5 Quebec municipal tree inventories to develop a database in which trees of each species (minimum of 20 trees per species) were classified into DBH percentiles. Trees with a DBH that has reached or exceeded the 95th percentile of all DBH are considered “old.”

SylvCiT also estimates (quantitatively and monetarily) ecosystem benefits such as carbon storage and the social cost of carbon, as well as the ornamental value of urban trees. Ornamental value is also called structural value, for example in *i-Tree Eco*. This value is determined by the purchase cost of the largest tree of the same species available in a nursery, the current size of the tree (DBH), a species factor (e.g., high for red oak and low for gray birch), the condition of the tree, and its location (SIAQ 1995). For instance, the 236 selected trees in an area of the Old Port of Montreal (Figure 2B) have a total ornamental value of \$160,000 CAD.

SylvCiT estimates carbon storage from aboveground (wood, branches, bark) and belowground (roots) natural forest tree biomass equations. Aboveground equations based on DBH are available for 33 tree species; if the species is not one of these 33, equations for groups of hardwood or softwood species are used (Lambert et al. 2005). Belowground biomass is estimated from aboveground biomass with the equations developed by Li et al. (2003). Total biomass is multiplied by a factor of 0.8 to adjust for

the difference between urban and forest trees and then by 0.5 to evaluate carbon storage (Nowak and Crane 2002). The social cost of this stored carbon is also given. The social cost of carbon is a theoretical estimation of the expected costs of climate change resulting from the emission of an additional ton of carbon dioxide into the atmosphere in a given year. It is estimated in 2022 at \$193.30 CAD/ton of carbon (ECCC 2020).

## PLANTING RECOMMENDATIONS

The recommendation interface allows the user to choose the number of trees to add to the selected area and to specify some preferences that will be considered when recommending functional groups and species to plant. Traditional species selection tools use manual filters, whereas SylvCiT is a spatially explicit system that uses artificial intelligence (AI)-based approaches to maximize ecological weighted factors. First, the functional group diversity is maximized as a default function to ensure better resilience to global change. Then, the other factors (e.g., species diversity, species richness, carbon storage) are weighted by the user (from 1 to 10). A score is given to each possible candidate by a maximization heuristic that compares the weighted score given to every possible species combination according to user preferences.


The functional groups and the species that would bring about the greatest improvement in diversity and benefits are presented. The user can select different species from the produced list of recommended species to simulate a plantation (Figure 3A). Managers may be careful to avoid favoring only a few species or always the same species. A brief overview of what is gained when these species are planted is presented when selecting ‘*Update values.*’ For the example of the Old Port of Montreal, the analysis of the selection reflects the low species and weak functional group diversity of this area. Simulating a plantation of 20 trees (4 trees per species) would increase the functional group richness from 5 to 10 and the functional group diversity from 2.43 to 3.39 (Figure 3A).

A more detailed portrait of the selected area offers a comparison of *before* and *after* planting the new trees and allows the user to visualize the increase in diversity and carbon storage associated with the new species planted (Figure 3B). In the current version, the analyses are completed after the simulation of a plantation as if the newly planted trees had reached a

### A Simulating a plantation


Species of selected groups\*

Search...




**Quercus rubra**  
Functional Group: 4A

Number of trees:  More details




**Betula platyphylla**  
Functional Group: 5

Number of trees:  More details




**Aesculus indica**  
Functional Group: 2B

Number of trees:  More details




**Amelanchier canadensis**  
Functional Group: 3A

Number of trees:  More details



**Abies concolor**  
Functional Group: 1A

Number of trees:  More details



**Juglans nigra**  
Functional Group: 4A

Number of trees:  More details

**Important note**  
To optimize your plantation, it is strongly recommended to diversify your choice of species and functional groups.  
(\* Please note that the list is displayed in random order)  
Some municipalities prohibit the planting of this species or request that a minimum distance to infrastructure be respected (or other condition)

Update values

Plant selected trees			
Aspect	Current value	Future Value	Improvement
Species richness	12	17	41.67%
Species diversity	4.53	6.01	32.56%
Func group richness	5	10	100.00%
Func group diversity	2.44	3.39	39.13%
Carbon Storage	18412.10	19226.72	4.42%

Page 1 of 1  
10 rows

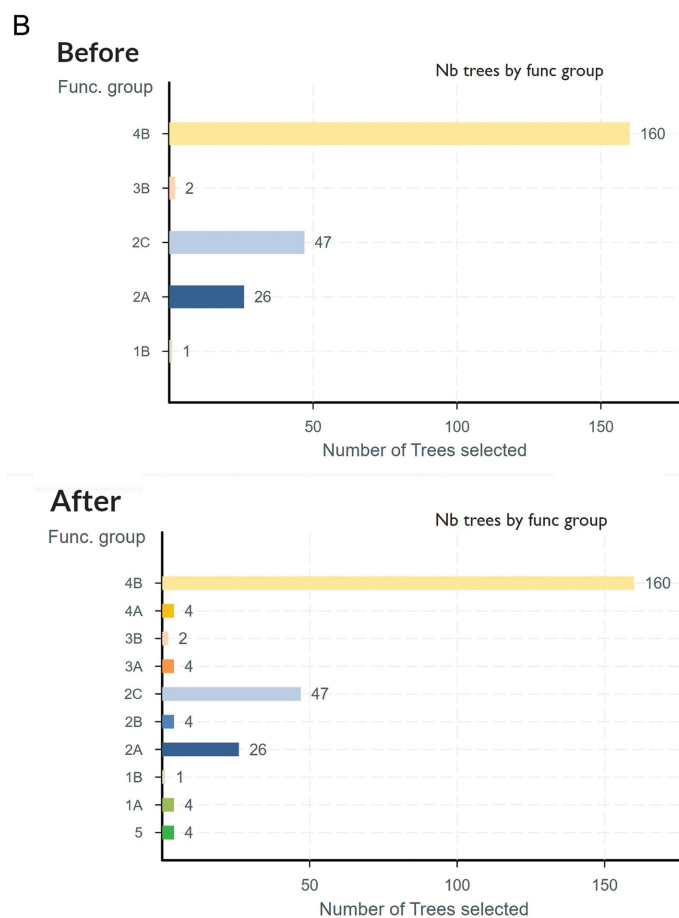


Figure 3. ‘*Simulating a plantation*’ allows the user to choose species from among those recommended and to see the improvements in richness, diversity, carbon storage (A), and the changes in the distribution of trees per functional group *before* and *after* the simulation of a plantation (B).

DBH of 15 cm (i.e., a decade or so after planting) and do not consider the growth of the other trees already present in the selected area. However, as the tool is improved, an AI-based growth prediction algorithm will be included in the source code to provide a better portrait after 10, 20, or 30 years, including the growth and possible mortality of existing trees.

## CONCLUSION AND FUTURE RESEARCH

SylvCiT is a user-friendly software integrated into a web platform that can be a tree explorer, a tool to assess different indices of tree diversity and ecosystem benefits in a selected urban forest area, and can provide planting recommendations to maximize species and functional group diversity as a way to increase the overall resilience of the urban forest to future uncertain disturbances. Despite an increase in the integration of AI into new decision-making tools, such as *Dylogos* that assesses tree risk (Rust and Stoinski 2022), NatureScore (NatureQuant 2023), or *ecoTeka* (Natural Solutions 2022), SylvCiT is the first open-source tool using AI to suggest appropriate tree species based on the functional diversity approach and on factors weighted by the user via a recommendation algorithm. Other factors like mitigation of urban heat islands will eventually be added to the recommendation algorithm to propose species adapted to drier and warmer conditions and/or species that can help decrease urban heat islands. The prediction of diameter growth provided by a machine learning-based algorithm will soon be integrated into the tool and will help to plan tree maintenance and tree replacement. Our dynamic predictive model will be able to forecast forest growth over the years by combining input from the environment, like temperature or the presence of diseases, as well as internal factors, like species and health conditions.

The software is currently being tested by municipal partners who make suggestions for its improvement. For example, due to an increased interest in using a 5-10-15 ratio (no more than 5% of a species, no more than 10% of a genus, and no more than 15% of a family) instead of the 10-20-30 rule (Galle et al. 2021), this benchmark will be available in 2023. Our ongoing work aims to consolidate new databases so the tool can be used in other geographic areas and to improve the tool with the addition of new functions and modules. For instance, we are exploring tree-soil biodiversity relationships to include soil characteristic

data in the recommendation algorithm. We will also integrate new ecosystem services to estimate the effects of urban trees on water runoff mitigation or urban heat island mitigation. These additions will assist urban forest managers as well as citizens interested in increasing urban tree diversity and improving resilience to global change.

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**Conflicts of Interest:**

The authors reported no conflicts of interest.

*Appendix on next page*

**Appendix. Urban forest software, applications, and tools.**

<b>Name of the tool</b>	<b>Company/institution</b>	<b>Website</b>
Arboclimat and Arbre-en-Ville	NEPSEN Transition, Atelier Colin & Poli Paysages (ACPP)	<a href="http://www.arbre-en-ville.fr/arbre-en-ville">http://www.arbre-en-ville.fr/arbre-en-ville</a>
Citree	Technische Universität Dresden	<a href="https://citree.de/?language=en">https://citree.de/?language=en</a>
i-Tree Species	USDA Forest Service, Davey Tree Expert Company, The Arbor Day Foundation, Society of Municipal Arborists, ISA, Casey Trees, SUNY College of Environmental Science and Forestry	<a href="https://species.itreetools.org">https://species.itreetools.org</a>
Right Place Right Tree–Boston	Boston University Biogeoscience and URBAN graduate programs	<a href="https://zoeywerbin.shinyapps.io/Boston_trees">https://zoeywerbin.shinyapps.io/Boston_trees</a>
Select Tree	Urban Forest Ecosystems Institute, California Polytechnic State University	<a href="https://selecttree.calpoly.edu">https://selecttree.calpoly.edu</a>
SESAME	Cerema, Ville de Metz and Metz Métropole	<a href="https://metz.fr/projets/developpement-durable/sesame.php">https://metz.fr/projets/developpement-durable/sesame.php</a>
Tree Advisor	USDA National Agroforestry Center	<a href="https://www.fs.usda.gov/nac-plant-guide">https://www.fs.usda.gov/nac-plant-guide</a>
Tree Planting Predictor™ Tool	Edge Environment	<a href="https://edgeenvironment.com/treeplantingpredictor">https://edgeenvironment.com/treeplantingpredictor</a>
Which Plant Where	Macquarie University	<a href="https://www.whichplantwhere.com.au">https://www.whichplantwhere.com.au</a>
EcoServR	Liverpool John Moores University, Natural Capital Solutions, Forest Research, and the Cheshire Wildlife Trust	<a href="https://ecoservr.github.io/EcoservR">https://ecoservr.github.io/EcoservR</a>
i-Tree Eco, i-Tree Design, MyTree	Same as i-Tree Species	<a href="https://www.itreetools.org/tools/i-tree-eco">https://www.itreetools.org/tools/i-tree-eco</a> ; <a href="https://design.itreetools.org">https://design.itreetools.org</a> ; <a href="https://mytree.itreetools.org">https://mytree.itreetools.org</a>
OpenTreeMap	AZAVEA, INC.	<a href="https://opentree-map.github.io">https://opentree-map.github.io</a>
Social Values for Ecosystem Services (SolVES)	USGS	<a href="http://solves.cr.usgs.gov">http://solves.cr.usgs.gov</a>
Urban InVEST	Natural Capital Project	<a href="https://naturalcapitalproject.stanford.edu/software/urban-invest">https://naturalcapitalproject.stanford.edu/software/urban-invest</a>
ENVI-met	ENVI-met GmbH	<a href="https://www.envi-met.com">https://www.envi-met.com</a>
Greenpass	GREENPASS GmbH	<a href="https://greenpass.io/software">https://greenpass.io/software</a>
Computational fluid dynamics software	e.g. SimScale, OpenFoam	<a href="https://www.simscale.com/product/cfd">https://www.simscale.com/product/cfd</a> ; <a href="https://www.openfoam.com">https://www.openfoam.com</a>
Exploring Tree Equity in Boston	Speak for the Trees, Boston	<a href="https://bucas.maps.arcgis.com/apps/MapSeries/index.html?appid=34e653bf29e64b72a64e78a175732b34">https://bucas.maps.arcgis.com/apps/MapSeries/index.html?appid=34e653bf29e64b72a64e78a175732b34</a>
Falling Fruit	Falling Fruit	<a href="https://fallingfruit.org">https://fallingfruit.org</a>
Google Earth Engine Apps	Tree Canopy Lab (e.g., Los Angeles)	<a href="https://insights.sustainability.google/labs/treecanopy">https://insights.sustainability.google/labs/treecanopy</a>
Healthy Trees, Healthy Cities	The Nature Conservancy, US Forest Service, and the Center for Invasive Species and Ecosystem Health at the University of Georgia	<a href="https://healthytreeshealthycitiesapp.org">https://healthytreeshealthycitiesapp.org</a>
i-Tree canopy, i-Tree Landscape, OurTrees	Same as i-Tree Species	<a href="https://canopy.itreetools.org">https://canopy.itreetools.org</a> ; <a href="https://landscape.itreetools.org">https://landscape.itreetools.org</a> ; <a href="https://ourtrees.itreetools.org">https://ourtrees.itreetools.org</a>
New York City Street Tree Map	City of New York, NYC Parks	<a href="https://tree-map.nycgovparks.org/tree-map">https://tree-map.nycgovparks.org/tree-map</a>
Many other cities with similar platforms	e.g., Seattle, San Francisco, Los Angeles (USA) Montréal, Québec, Ottawa (Canada)	<a href="https://www.seattle.gov/trees/get-involved/explore-trees-online">https://www.seattle.gov/trees/get-involved/explore-trees-online</a> ; <a href="https://www.quebio.ca/fr/arbresmtl">https://www.quebio.ca/fr/arbresmtl</a> ; <a href="https://open.ottawa.ca/datasets/ottawa::tree-inventory/about">https://open.ottawa.ca/datasets/ottawa::tree-inventory/about</a>
MapMyTree	European Environment Agency	<a href="https://mapmytree.eea.europa.eu/#/home">https://mapmytree.eea.europa.eu/#/home</a>

**Appendix. Continued.**

<b>Name of the tool</b>	<b>Company/institution</b>	<b>Website</b>
OpenTrees.org	Steve Bennett, freelance web developer	<a href="https://opentrees.org">https://opentrees.org</a>
Tree Equity Score Analyser	American Forests	<a href="https://www.treeequityscore.org">https://www.treeequityscore.org</a>
Treepedia	MIT Senseable City Lab, World Economic Forum	<a href="https://senseable.mit.edu/treepedia">https://senseable.mit.edu/treepedia</a>
TreeKeeper Canopy	Davey Tree Expert Company	<a href="https://canopy.treekeepersoftware.com/goshenin">https://canopy.treekeepersoftware.com/goshenin</a>
ArborPro	ArborPro, Inc.	<a href="https://arborprousa.com">https://arborprousa.com</a>
ArborScope™	Bartlett Tree Experts	<a href="https://www.bartlett.com/management-software.cfm">https://www.bartlett.com/management-software.cfm</a>