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100K Trees

WP 3: Tree Attributes

Deliverable 3.2: Tree attributes final version

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List of Acronyms

CNN	Convolutional Neural Network
LAI	Leaf Area Index
NDVI	Normalized Difference Vegetation Index
RGB	Red-Green-Blue (colors for orthophotos)
RGBIr	Red-Green-Blue and Infrared (colors for orthophotos)
WP	Work package

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Executive Summary

Deliverable 3.2 (D3.2) is a summary of the process of obtention of the key tree attributes needed for ecosystem service modelling in work package 4 (WP4).

Indeed, D3.1 was a science-based list of key tree attributes for calculating the contribution of each individual tree to the six ecosystem services central to the 100kTREES project. It ended with a very brief review of the available data. This deliverable has been used as a basis for the exploratory work in WP4 and has led to a final list of essential tree attributes for ecosystem modelling.

It is that list that is the basis of the present document.

Through remote sensing, field work, literature research and database inquiries, most of the needed information has been acquired, documented, and provided to the modelling experts of WP4. This process has been a collaborative effort between WP2, WP3 and WP4 and its results are discussed and documented in this deliverable.

After a short description of the document's purpose, audience, and structure in chapter 1, chapter 2 describes the overall process touched briefly above, chapter 3 then documents the different sources of information that have been used, while chapter 4 dives into the detail of the data available for each tree attribute required for modelling. The conclusions of this deliverable are summarized in chapter 5 and the references are given in chapter 6.

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1 Introduction

1.1 Purpose and audience of the document

This deliverable is the continuation of the previous deliverable of work package 3. Indeed, D3.1 described the most important tree attributes for modelling the contributions of individual trees to the main ecosystem services treated in the 100kTREES project, and this deliverable describes the available data on those tree attributes in line with WP4 needs. D3.2 is somewhat the practical counterpart of the more theoretical D3.1.

D3.2 serves mainly internal purposes for documenting the lessons learned in obtaining the tree attributes for ecosystem modelling. It is shared with project partners and EC auditors to set a solid methodological base for the input needs of the 100kTREES' toolbox. It will be made available publicly for transparency.

1.2 Structure of the document

After the introduction, the process of producing a final list of attributes for modelling individual tree contributions to the ecosystem services together with the colleagues of WP4, is documented in chapter 2, which ends with the list of data sources for those attributes. Those data sources are described with more detail in chapter 3. In chapter 4, the information obtained in the process is documented per attribute. Chapter 5 serves as conclusion and the reference list is given in chapter 6.

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2 Assessing the ecosystem services provided by trees through their attributes

100kTREEs' aim is to make cities a better place to live by supporting the efficient planting of trees for increasing the ecosystem services provided by them. The ecosystem services the project is concentrating on, are:

- Urban Pluvial Flood Inundation and Damage Assessment,
- Air Pollution and $PM_{2.5}$, PM_{10} & NO_2 reduction,
- Tree Noise Absorption and Impact on Traffic Noise Distribution,
- Biodiversity and Carbon sequestration,
- Urban Cooling Assessment.

These ecosystem services have been thoroughly explored in deliverable 3.1 (Vanwildemeersch et al., 2023), first through an extensive literature review of the available scientific literature documenting the links between urban trees and the ecosystem services they provide. For each ecosystem service considered in the project 100kTrees, a list was constructed with the most important tree attributes useful for modelling the tree's contribution to the ecosystem service. Subsequently, the tree attributes relevant for modelling the ecosystem services provided by individual trees were retained and fully described. That description included methods and data sources for filling eventual data gaps.

The list of retained tree attributes and for which ecosystem service they are important:

Attribute	Ecosystem service
Allelochemicals	Biodiversity improvement
Clearance height	Cooling effect
Crown diameter (canopy projection area)	Air pollution reduction, Cooling effect, Noise abatement
Crown form	Cooling effect
Diameter / circumference of the trunk at breast height	Air pollution reduction, Biodiversity improvement, Cooling effect, Noise abatement, Potential carbon mitigation
Leaf Area Index (LAI)	Air pollution reduction, Cooling effect, Flood risk and estimated damages, Noise abatement
Presence of moss on trunk	Noise abatement
Pruning regime	Biodiversity improvement, Potential carbon mitigation
Radial roughness	Noise abatement
Species specific transpiration	Cooling effect
Tree height	Air pollution reduction, Cooling effect, Noise abatement, Potential carbon mitigation
Tree physiological status (health status of the tree)	Air pollution reduction, Cooling effect¸ Potential carbon mitigation
Tree planting date	Noise abatement, Potential carbon mitigation
Tree species	Air pollution reduction, Biodiversity improvement, Flood risk and estimated damages, Noise abatement, Potential carbon mitigation

Table 2-1. List of attributes for modelling individual tree contributions to the ecosystem services (Vanwildemeersch et al., 2023).

After review by the modelling experts of the project, allelochemicals, presence of moss on trunk and radial roughness have been considered of lesser importance and too difficult to obtain at this stage of the project. Special attention was drawn by the same experts on three

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extra attributes, namely Normalized Difference Vegetation Index (NDVI), phenological data and soil sealing percentage.

NDVI was considered particularly useful for monitoring tree health, which also influences tree growth rate (thus the temporal aspect of crown diameter and tree height). Phenological data was needed to include the seasonality of LAI in the model. Soil sealing within the crown projection was needed as an indicator of the environment's growing potential for the tree, so to correct the growth model with information on the tree's environment.

This brought the final list of tree attributes needed for tree modelling to the one presented in the next table:

Attributes
Clearance height
Crown diameter
Crown form
Diameter / circumference at breast height
Leaf Area Index (LAI)
NDVI
Phenological data
Pruning regime
Soil sealing percentage (under trees)
Species specific transpiration
Tree height
Tree physiological status (health status and percentage missing crown)
Tree planting date
Tree species

Table 2-2. Final list of attributes for modelling individual tree contributions to the ecosystem services.

In brief, it should be possible to calculate the impact of any urban tree on the ecosystem services, if those attributes are known.

So, logically, the attributes were then looked for, first in existing databases and in scientific literature, then through remote sensing, and finally by inventorying a sample of trees. As a summary, the next data sources have been made available to the project partners:

1. (Sofia) OneTree ('Едно Дърво') Initiative urban tree database (OneTree database, n.d.), which has data input coming from tree experts as well as from citizen scientists through their mobile application,
2. (Sofia) Sofiaplan ('Софияплан') tree map obtained by automated analysis of remote sensing data (Trees index, n.d.),
3. (Copenhagen) Municipal tree database (Kommunale traeer, n.d.) which has input coming from tree experts,
4. The tree knowledge database, a result of an extensive literature review by OneTree Foundation,
5. (Copenhagen) The Copenhagen tree map, obtained by automated analysis of remote sensing data within 100kTREEs (Eurosense, 2023),
6. (Sofia) The Sofia tree map, obtained by automated analysis of remote sensing data within 100kTREEs (Eurosense, 2024),

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7. (Copenhagen) The Copenhagen tree sample inventory (Copenhagen tree sample, 2023).

The municipal tree database from Copenhagen as well as both tree databases from Sofia existed before 100kTREEs and were made available by the respective database owners. The tree knowledge database was developed by OneTree Foundation before this project and has been extended and translated for improving its compatibility with ecosystem service modelling. The Copenhagen and the Sofia tree maps were developed by the project partner Eurosense as part of the tasks planned for WP2. And the Copenhagen tree sample inventory has been obtained through field work by a collaboration between the project partners C-WARE and EcoTree within task 3.2 (filling in missing data). The NDVI dataset is still to be created by Eurosense for WP2, so that dataset is not yet included in the previous list.

The next chapter gives more details on each of the data sources.

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3 Our data sources

Before tackling the information obtained per attribute, a short description is given of the different data sources that have been found and/or created for this purpose.

3.1 OneTree ('Едно Дърво') Initiative urban tree database

The OneTree Foundation manages a GIS database of trees in urban areas of Bulgaria, available at ednodarvo.io (OneTree database, n.d.). This database includes point objects with detailed attributive information, which are stored in a PostgreSQL database. For the 100KTREES project, OneTree Foundation has translated the ednodarvo.io platform, including all tree attributes and their values, into English and Danish.

The primary goal of this database is to store and provide information (amongst others as open data) that assists in the conservation and management of urban trees. The ednodarvo.io platform supports automatic data export in various formats for trees located within user-defined project boundaries by authorized users. Data entry on ednodarvo.io can be done by citizen contribution or expert opinion through two distinct modules:

- **Citizen Module**: Designed for data entry by non-professionals, based on a crowdsourcing principle.
- **Expert Module**: Used by semi-professionals (students and urban planners) and professionals (such as tree experts, landscape architects, and dendrologists), this module provides more detailed data entry and verification.

Both modules are designed to support the historical layering of information, ensuring each modification is documented with the date and user details. Additionally, ednodarvo.io provides tools for remote, expert verification of information entered by non-professionals, alongside systematic accuracy checks.

The data collected and managed through ednodarvo.io is organized into several categories, each with specific attributes:

- **Geographic Location**: Exact positioning of each tree.
- **Biometry**: Includes the approximate age of the tree (determined by experts), overall height, trunk height, crown diameter, type of trunk structure, and trunk diameter.
- **Photographic Materials**: Captures the overall habitus, leaves/needles, branches, bark, flowers, and fruits.
- **Taxonomic Information**: Distinguishes between the taxonomic genus (citizen module) and species (expert module).
- **Damages and Peculiarities**: Details general conditions, base, trunk, and crown aspects.
- **Health Assessment** and **Maintenance Recommendations**: Provided exclusively through the expert module.

These categories are non-mandatory, as not all attributes are relevant in every context. This flexible structure aims to encourage and facilitate the participation of citizen volunteers in the process of mapping urban trees.

When using the database, it is important to consider that:

- Information about trees may often be incomplete or outdated.

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- A distinction should be made between data entered by non-professionals and data filled or verified by experts.
- The accuracy and relevance of data filled by non-professionals may vary, and potential errors should be considered.

3.2 Sofiaplan (‘Софияплан’) tree map

Sofiaplan, a municipal enterprise located in Sofia, Bulgaria, has developed a database encompassing all the trees within the Sofia municipality (Trees index, n.d.). This database primarily utilizes a Machine Learning (ML) algorithm adapted from DeepForest (DeepForest documentation website, n.d.), which is specialized in identifying individual tree crowns from orthophoto imagery. This algorithm was trained using 500 examples of expertly identified tree crowns to ensure accuracy. From this process, the database not only captures the approximate locations of each tree (centroids) but also calculates the average diameter of the tree crowns by averaging the total extent measurements.

In addition to spatial data, the database is enriched with elevation details for each tree. These details are meticulously aligned with Sofia municipality's detailed elevation maps, which are also produced by Sofiaplan.

Furthermore, the database includes classifications of each tree into the categories - broadleaf, coniferous, or undefined. This classification is derived from intersecting the tree location data with the "Dominant Leaf Type" layer from the 2018 Copernicus Land Monitoring Service High Resolution dataset.

It's important to note that this dataset is based on an orthophoto taken in the fall of 2020 and is considered a one-time dataset. Currently, there are no confirmed updates scheduled for the near future. This dataset has been made available for the 100KTREES project, facilitated through a collaboration between the OpenTree Foundation and Sofiaplan.

Sofiaplan intends to make this tree recognition data publicly accessible as open data, which will be available on their website in the open data section.

The accuracy of the attributive information within the database varies depending on the attribute and the methodology employed in obtaining these values. The overall accuracy of the map is reported to be around 80%. While this indicates a generally reliable dataset, it's important to note the possibility of discrepancies or inaccuracies.

3.3 Database ‘Kommunale traeer’

The municipality of Copenhagen maintains a dataset known as the *Kommunale Traeer* Database (Kommunale traeer, n.d.), which includes most of the trees with maintenance responsibility for the municipality.

The access to the dataset is facilitated through the platform [Open Data DK](), where it is available as an open-source dataset in the downloadable formats .json and .csv and viewable through a web map interface. The dataset is regularly updated by the municipality to ensure its continuity.

The attributes from this database relevant for the 100k trees project include clearance height, crown diameter, tree height, physiological status, planting date, and species information. These attributes are mainly retrieved via expert field visits in Copenhagen. However, it's

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important to note that not all these attributes are uniformly distributed across all records (see chapter 4 The tree attributes).

This dataset is delivered *as is*, so without metadata or a description of the methods used. This has been confirmed by email after reaching out to the responsible instances.

3.4 The tree knowledge database

OneTree Foundation maintains an extensive database on tree species found throughout Bulgaria. Known as "Knowledge of Trees in Bulgaria", this database is continuously updated and includes the following main categories of data about tree species:

- Morphological characteristics,
- Phenological characteristics,
- Environmental condition requirements (what does the tree need),
- Environmental resilience (what stressors can the tree withstand),
- Ecosystem benefits for people and the environment,
- Health risks to humans,
- Types of utilization of tree species in urban settings.

The database is stored in a PostgreSQL database and is managed by the team at the OneTree Foundation. The information in the database is the result of an extensive literature review combined with expert observations.

At the current stage of the 100KTREES project, only a portion of the attributive information contained in the database is relevant. As a partner in the project, the OneTree Foundation team focuses on collecting information about tree species according to the following attributes:

- Tree species found in the Sofia Municipality,
- Crown form,
- Phenological data.

3.5 The 100kTREEs Copenhagen tree map

At the time of the 100kTREEs project a complete tree dataset of Copenhagen was lacking. Since the critical need of this data in WP4's model, Eurosense produced in 2023 a tree database for Copenhagen (Eurosense, 2023). This database includes the tree locations of all trees of Copenhagen, alongside key attributes including crown diameter, Leaf Area Index (LAI), tree height, and tree health.

These tree locations and dimensions were obtained via Individual Tree Detection using LiDAR data from 6/4/2019. While the LiDAR dataset used for the database creation dates to 2019, a new LiDAR flight has been planned over Copenhagen for 2024, which indicates that this database could be updated more or less every five years. The attributes of Leaf Area Index (LAI) and tree health were derived from summer orthophotos captured in 2017. As these orthophotos are not publicly accessible in Copenhagen, we obtained the dataset from DHI, which explains the time gap between the dataset creation (2023) and its source (2017). Since the difficulty in obtaining summer orthophotos for Copenhagen no update of the LAI and crown vitality are planned for now. Further details regarding the calculation methodologies for each attribute can be found in chapter 4.

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The database is owned by Eurosense and hosted on their servers. Access is upon request.

3.6 The 100kTREEs Sofia tree map

Similarly to Copenhagen, a comprehensive tree dataset was required for Sofia in this project. Sofiaplan had already compiled this dataset based on orthophotos from 2020 (section 3.2). Eurosense enhanced the Sofiaplan tree database in 2024 by incorporating additional tree attributes: tree height, LAI, and crown vitality (Eurosense, 2024). Tree height was derived from a Digital Surface Model (DSM) of Sofia from 2020, while LAI and crown vitality were based on the summer orthophotos of the same year. It is important to note that this dataset is a one-time dataset, and no updates are currently scheduled. Further details regarding the calculation methodologies for each attribute can be found in chapter 4.

The extended database is owned by Eurosense and hosted on their servers. Access is upon request.

3.7 The Copenhagen tree sample inventory

WP4 considered that a recent sample of specific trees in Copenhagen could greatly improve their models' accuracy. That is why a Copenhagen tree sample inventory was done at the end of 2023 and the beginning of 2024 (Copenhagen tree sample, 2023). Within the combined Sofia and Copenhagen datasets, the 5 most frequently occurring species were identified. Those species received subsequently a weight according to their importance in the original datasets. 200 trees were then randomly chosen in Copenhagen for extra measurements. The sample was evaluated to be representative by the large dataset (combining Sofia and Copenhagen data).

These trees were then examined directly in the field, thanks to the collaboration of CWare and EcoTree, to record the following attributes on each of them:

- Species (among the 5 most abundant in Copenhagen),
- Diameter at breast height /1.30m (DBH),
- Total height of the tree,
- Crown size,
- Overall health of the tree,
- Pruning regime.

The attributes collected on each tree were then compiled in an Excel file and sent directly to WP4.

Regarding data quality, WP3 and WP4 judged that 200 measurements were sufficient to achieve good accuracy, while limiting the amount of fieldwork. Some measurements could not be taken because some trees were inaccessible (they were located between freeway lanes) and some had been cut down. However, the number of unmeasured trees was minimal and did not affect data quality. A final point of caution concerns the sampling period, which took place in winter. The absence of leaves on the trees made species identification and assessment of tree health more complicated. Error rates remain low, however, and the size of the sample will enable any errors to be corrected.

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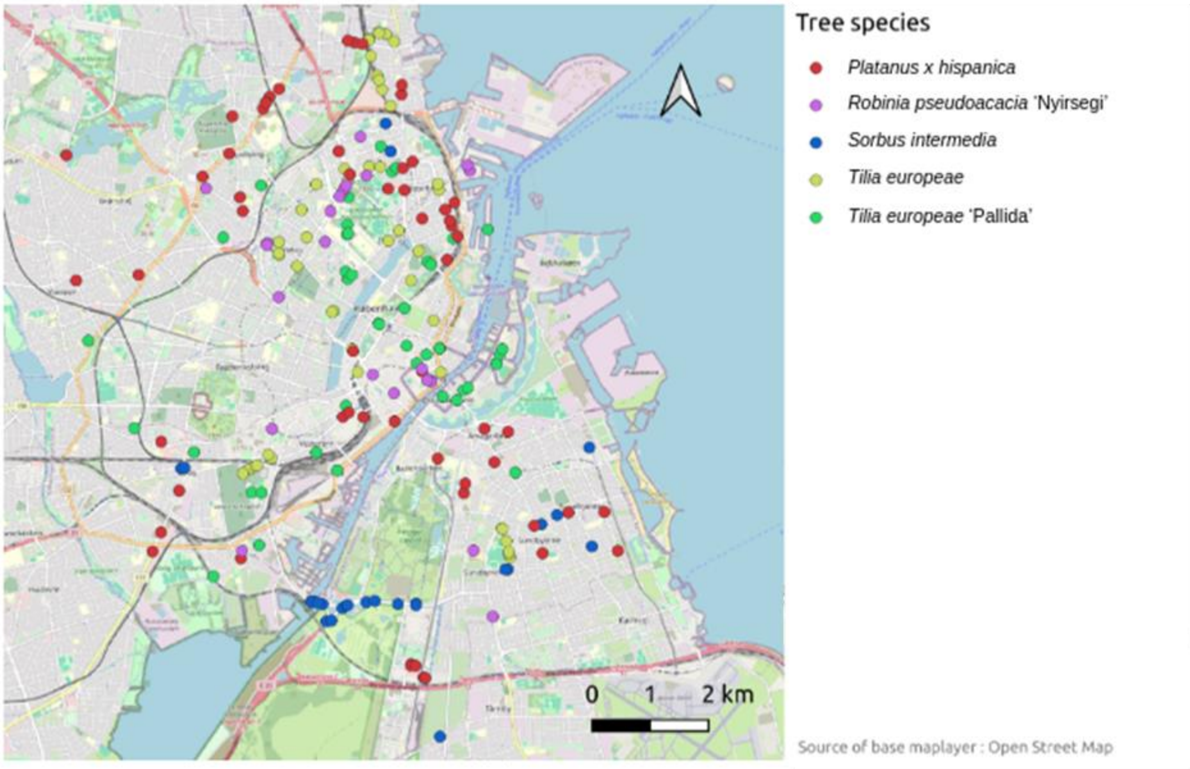

Figure 3.1 Map of the 200 trees measured in Copenhagen as part of the inventory.

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4 The tree attributes

Most of the 14 tree attributes asked for by WP4 have been found or developed between M6 and M18 of the 100kTREES project. That process is described very briefly in the next subchapters per attribute, and where possible, the results have been discussed.

4.1 Clearance height

The clearance height in the Copenhagen tree sample was measured by using the app Arboreal Træ (Arboreal Tree, n.d.). The app works by first walking close to the stem of the tree to mark the tree. Then move away from the tree about the same distance as the height of the tree while keeping the phone in an upright position. Then the base and the top of the tree need to be marked and then the clearance height can be measured. The results are within a few percent. This has been done for all 200 trees in the sample.

In the OneTree Initiative Urban Tree Database, the attribute "Clearance height" is listed under the name "biometry_trunk_height". The values for this attribute are presented in meters as whole numbers. As of April 23, 2024, data for 959 trees (788 broadleaves and 171 coniferous) is available under this attribute, representing a little over 4% of the total objects in the database. The data has been primarily collected by experts and "semi-experts" (4th-year students in the Landscape Architecture program).

4.2 Crown diameter

For the Sofiaplan tree map, the crown diameter attribute was calculated for all trees in **Sofia** and obtained through a crown size algorithm, representing the average diameter of trees crowns. The dataset offers one-meter resolution crown diameters for all trees in Sofia, with an overall dataset accuracy reported around 80%. Specific accuracy data for crown diameter is not available. However, no outliers could be detected in de dataset (Crown_diam > 30 m).

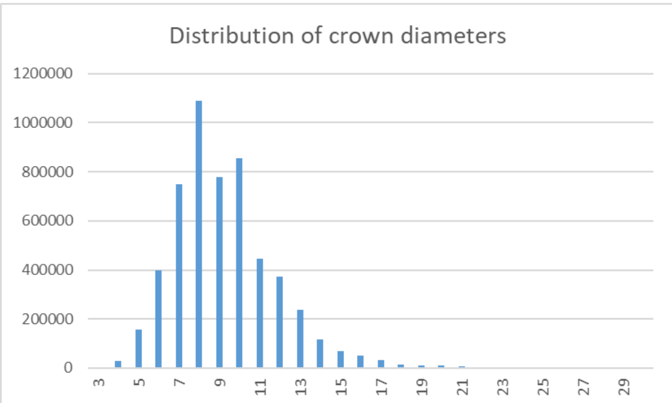

Figure 4.1 Distribution of the crown diameters in the Sofiaplan tree map.

The attribute ‘crown diameter’ is present in various databases for **Copenhagen**: the Copenhagen tree sample, the 100kTREEs Copenhagen tree map and the *Kommunale traeer* database.

While the *Kommunale traeer* database only partially includes crown diameter data, efforts were made during the project's scope to calculate crown diameters for all trees in Copenhagen. In the 100kTREEs Copenhagen tree map, crown diameters were calculated by Eurosense based on the maximal crown diameter from segmented LiDAR point clouds. The

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dataset contains 1.326 outliers (Crown_diam > 30 m) on a total of 297.832 identified trees. Those values were modified to NULL values in the dataset.

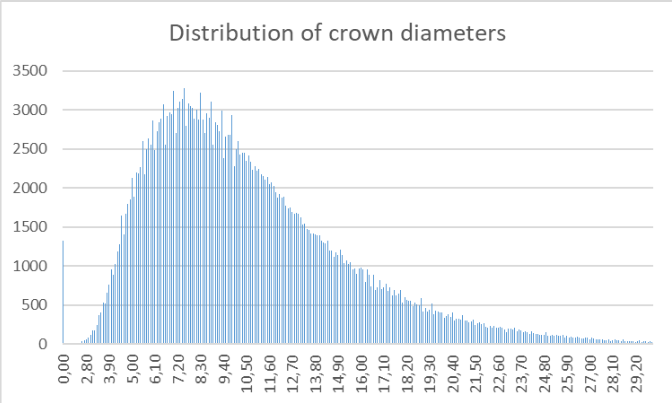

Figure 4.2 Distribution of the crown diameters in the 100kTREEs Copenhagen tree map.

The tree crown diameter in the Copenhagen Tree sample was measured for 200 trees by using the app Arboreal Træ (Arboreal Tree, n.d.). The app works by first walking close to the stem of the tree to mark the tree. Then we moved away from the tree about the same distance as the height of the tree while keeping the phone in an upright position and marking the base and the top of the tree and then the crown on each side. Then the application gives you the tree diameter displayed on the screen. The results are within a few percent.

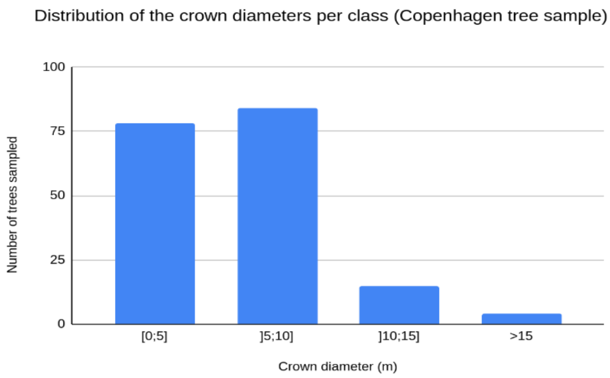

Figure 4.3 Distribution of the crown diameters per class in the Copenhagen tree sample.

Data for the attribute "Crown diameter" is available for 15.959 trees, representing just under 67% of the total number of trees in the OneTree Initiative urban tree database. Of these, 14.157 are ornamental broadleaves, 328 are fruiting broadleaves, and 1.474 are coniferous. In the Sofia tree database (OTF), the attribute "Crown diameter" is listed under the name "biometry_crown_diameter". The values for this attribute are in meters and are presented as whole numbers.

The data has been collected in the field by experts, semi-experts, and citizens. After additional review, this data could serve as a basis for calibrating algorithms for remote, automatic recognition of tree crowns from satellite and orthophoto images, as well as from point clouds.

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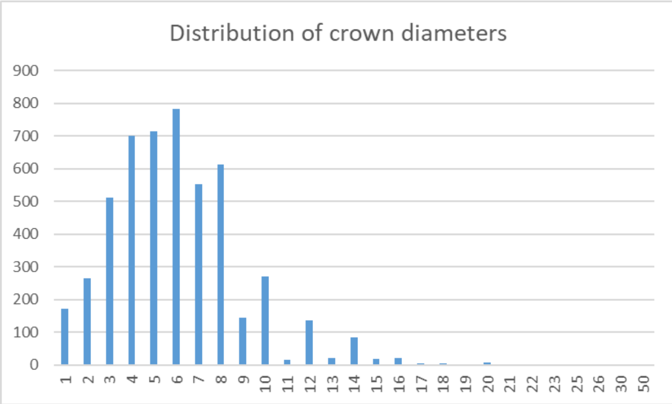

Figure 4.4 The distribution of height in the OneTree urban tree database.

4.3 Crown form

The attribute "Crown Form" is available in the tree knowledge database of the OneTree Foundation. This information has been collected through literature review and is determined at the tree species level. It is listed under the name "Crown Shape" and includes the following values:

- Broadly Pyramidal,
- Columnar,
- Conical,
- Elliptical,
- Globular,
- Inversely Ovate,
- Oval,
- Ovate,
- Pyramidal,
- Pyramidal (Narrowly),
- Rounded,
- Spreading (Irregular),
- Umbrella-Shaped,
- Weeping.

As of April 23, 2024, the team at the OneTree Foundation has gathered information on the characteristic crown form of 195 tree species, of which 149 are known to be found in Sofia. The crown shape at the species level is expected to be relatively consistent between both cities, but its values may vary slightly depending on specific environmental conditions (climatic, topographical, urban planning, etc.).

4.4 Diameter / circumference at breast height

The diameter of the tree trunk at breast height was measured in the Copenhagen Tree sample by using measuring tape for 200 trees. The measuring tape was first used to find the height of measurement at around 1,35 - 1,4m and afterward to measure the circumference. In a few cases, the tree had multiple trunks – in those cases, all trunks were measured at DBH height. There were also a few cases with some trunk deformities where the measurements were

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made just above or below. In those cases, the height that the measurement was made at was written down.

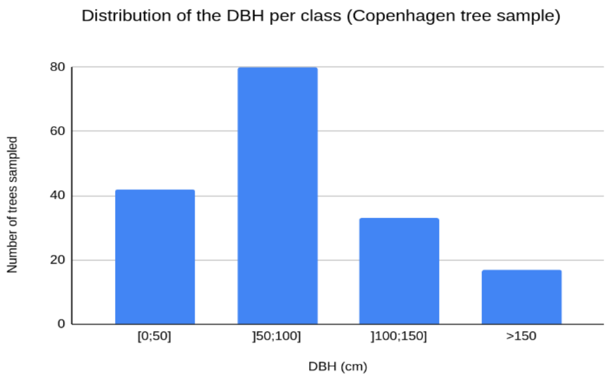

Figure 4.5 Distribution of the DBH per class in the Copenhagen tree sample.

Information for the attribute “Diameter / circumference at breast height” is also available in the OneTree Initiative Urban Tree Database under the name “biometry_trunk1_diameter”. The values for this attribute are presented in centimeters, rounded to the nearest even number, and stored as whole numbers.

As of April 23, 2024, the OneTree Initiative Urban Tree Database contains values for this attribute for 10,058 trees, of which 9,218 are ornamental broadleaves, 270 are fruiting broadleaves, and 570 are coniferous. These represent a little over 42% of the total number of trees in the database.

The data has been collected in the field by experts, semi-experts, and citizens using various methods:

- Direct measurement of the diameter using calipers,
- Measurement of the trunk circumference with a tape measure and automatic calculation of the diameter,
- Measurement of the trunk circumference using a span (with a pre-measured length) and automatic calculation of the diameter.

The first two methods are mainly used by experts and semi-experts, while the third method is used by citizens.

Additionally, the OneTree Initiative Urban Tree Database contains also an attribute named “biometry_trunk_branching”, which provides information about the type of trunk structure. This attribute includes the following values:

- 'single' — tree with a single trunk,
- 'low' — tree with a trunk branched below 130 cm,
- 'cluster' — multi-stemmed tree.

In cases where the value of the attribute is 'low' or 'cluster', the OneTree platform allows for the entry of information for the diameters of the five thickest trunks/branches. The values for these are recorded in attribute columns named “biometry_trunk1_diameter”, “biometry_trunk2_diameter” and so on, up to “biometry_trunk5_diameter”.

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4.5 Leaf Area Index (LAI)

While data of the Leaf Area Index (LAI) is not currently present in existing tree databases for Copenhagen and Sofia, efforts have been made by Eurosense to generate LAI datasets to meet the demands of Work Package 4 (WP4).

LAI values were derived through a least squares regression analysis using LAI field data collected with the PocketLAI application (PocketLAI, 2024) and RGBIr summer orthophotos from Brussels in 2023. This regression model was then applied to RGBIr summer orthophotos from Copenhagen in 2017 and RGB summer orthophotos from Sofia in 2020. This resulted in one LAI value per tree for each of the 297.832 trees in the 100kTREEs Copenhagen tree map and the 630.898 trees in the extended Sofiaplan tree map. The resulting LAI values represent a one-time dataset, as they are based on the availability of summer orthophotos for each city.

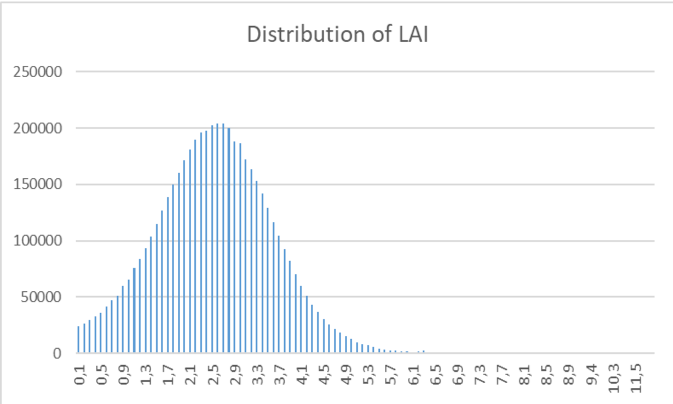

Figure 4.6 The distribution of LAI in the 100kTREES Sofia tree map.

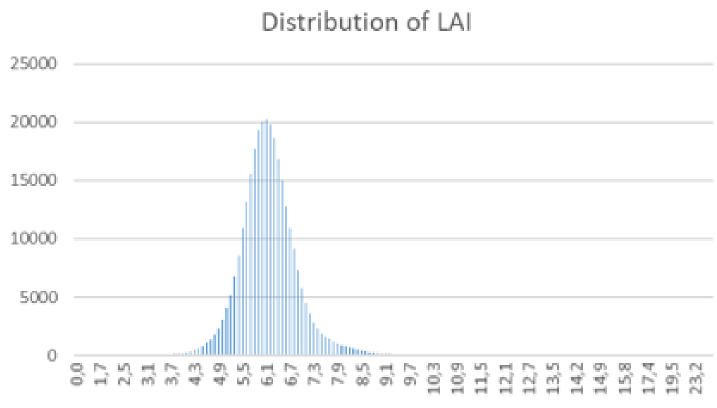

Figure 4.7 The distribution of LAI in the 100kTREES Copenhagen tree map.

4.6 NDVI

The Normalized Difference Vegetation Index (NDVI) is currently not available in existing databases for Copenhagen and Sofia. Therefore, efforts are being made in the scope of the 100kTREEs project to generate NDVI datasets to meet the demands of Work Package 4 (WP4) for high-resolution NDVI data.

For **Copenhagen**, two NDVI rasters could be calculated: one based on the summer orthophotos of 2017 with a resolution of 10 cm and the other using very-high resolution (VHR)

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satellite imagery from Airbus Pléiades Neo from summer 2022 with a resolution of 30 cm. Since both NDVI raster are one-time datasets, seasonal calculations are not feasible. However, seasonal NDVI for Copenhagen can be calculated using Sentinel-2 satellite images with a resolution of 10 m, offering valuable insights into vegetation dynamics throughout the year.

In the case of **Sofia**, NDVI calculation based on RGB orthophotos of 2020 was not possible due to the absence of Near-Infrared (NIR) bands. However, DHI provided a VHR satellite image (Airbus Pléiades Neo, 30 cm) from summer 2022 for which the NDVI could be calculated. Moreover, similar to Copenhagen, seasonal NDVI for Sofia can be calculated using Sentinel-2 satellite images with a resolution of 10 m, providing a comprehensive understanding of vegetation dynamics.

The NDVI raster for Copenhagen will be provided to WP4 via a shared FTP link on a Eurosense server, delivered in .tiff format.

4.7 Phenological data

Information related to this attribute is contained in a set of attributes in the "tree knowledge database" (OTF). All attributes contain information at the tree species level. The values for each attribute have been collected by the team at the OneTree Foundation through an extensive expert literature review. The information presented below is for tree species found in Bulgaria, specifically in Sofia.

It is important to note that phenological attributes are among those tree attributes significantly influenced by various environmental conditions, from the climatic zone to urban mesoclimatic conditions and local factors. For now, only the information for Sofia has been found and shared with WP4.

Attribute	Values	Information found on …
Growth	Fast, Slow	155 species (120 present in Sofia)
Deciduousness	Evergreen, Deciduous	129 species (100 present in Sofia)
Time of Flowering	Before Leafing, Spring, Summer, Autumn, Winter	134 species (104 present in Sofia)
Flowering Duration	Short Flowering (Up to 15 Days), Medium Duration (15 to 30 Days), Long Duration (Over 1 Month)	81 species (63 present in Sofia)
Autumn Coloration	Yellow, Orange, Red, Brown	106 species (84 present in Sofia)
Time of Leaf Fall	Early-Deciduous — leaves fall in the first half of autumn; Late-Deciduous — leaves fall in the second half of autumn.	54 species (43 present in Sofia)

Table 4-1. List of phenological attributes added to the Tree Knowledge Database (OTF).

This information has been uploaded and shared with WP4 in April, 2024.

4.8 Pruning regime

The pruning regime in the Copenhagen tree sample was only noted if the tree was cleared for a road, a bike lane or if a special pruning had been done like box pruning or pruning because of a house or wire. The rest of the trees had a normal pruning regime in the form of crown lifting and were therefore not noted. None of the trees in the sample had not been pruned.

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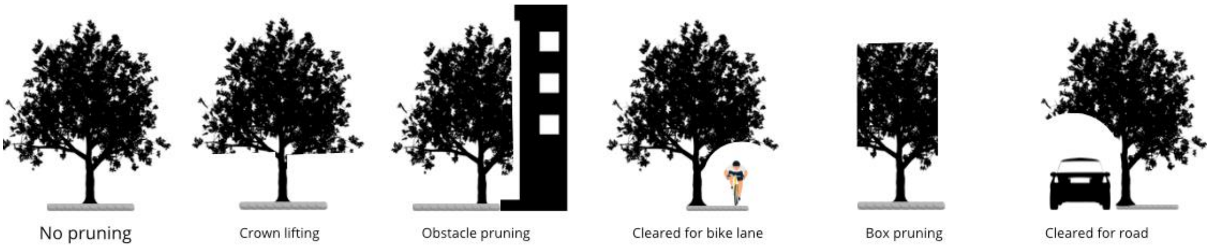

Figure 4.8 Pruning regime in the Copenhagen Tree sample inventory (source: 100KTREEs).

4.9 Soil sealing percentage (under trees)

Soil sealing percentage calculation through remote sensing was not carried out as part of this project due to it not being included in the initial proposal. Additionally, the allocated budget was needed for executing the planned tasks, leaving no resources available for additional analyses such as soil sealing percentage calculation.

4.10 Species specific transpiration

Species specific transpiration, although it is an interesting aspect of trees for calculating their impact on flood prevention and heat island reduction, is a very complex attribute (Vanwildemeersch et al., 2023). It depends strongly on the availability of water, on wind and air humidity, and of course, on tree size and species. The species factor as proposed in deliverable 3.1 was too simple to be efficient in modelling.

This aspect has been replaced by a simpler model for considering the effect of trees on flooding.

4.11 Tree height

In the database *Kommunale traeer* for Copenhagen, tree height data, labeled as "torso hoejde" was obtained through field data collection by experts. However, due to the incomplete coverage, efforts were made during the project to calculate tree height for all trees in Copenhagen.

In the 100kTREEs dataset for Copenhagen**,** the tree height was calculated based on points within the LiDAR point cloud with the largest distance above ground. Values start from 2.5 meters, which is the default input parameter used for LiDAR data segmentation. 297.832 tree heights have been calculated this way.

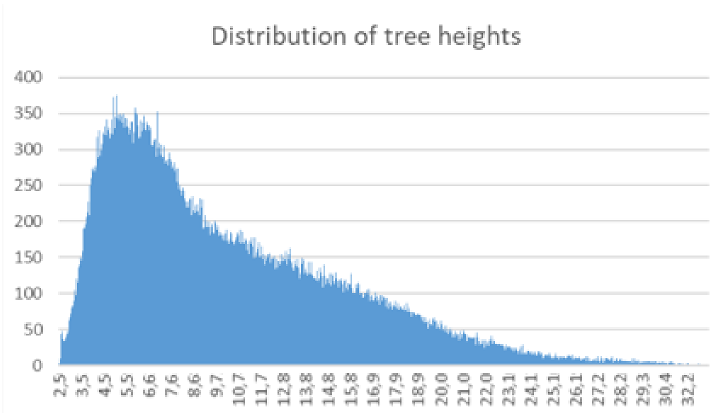

Figure 4.9 The distribution of height in the 100kTREES Copenhagen tree map.

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For Sofia, the DTM available in the Sofiaplan tree map was created by Sofiaplan. Tree height was then calculated by subtracting the DSM (Digital Surface Model) created by Eurosense from the DTM.

The tree heights were then added to the 100kTREEs datasets for Copenhagen and Sofia and were provided to Work Package 4 (WP4).

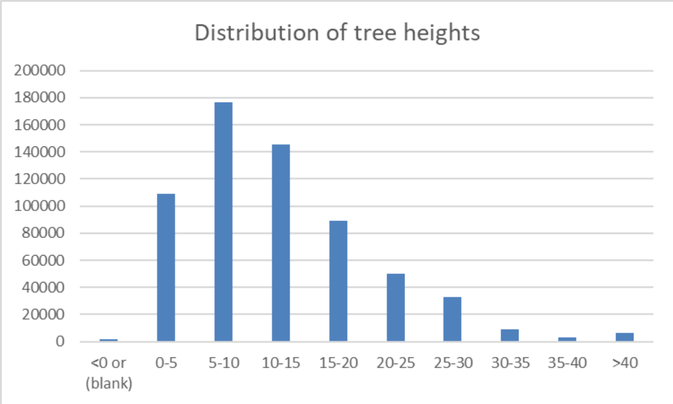

Figure 4.10 The distribution of height in the 100kTREES Sofia tree map.

5.100 tree heights have been documented in the OneTree Initiative urban tree database.

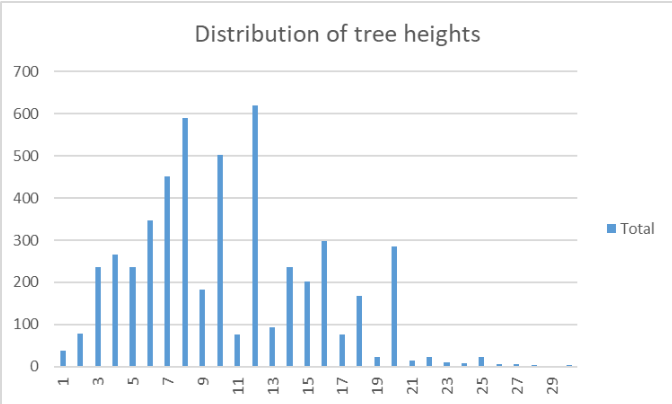

Figure 4.11 The distribution of height in the OneTree urban tree database.

The tree height in the Copenhagen Tree sample was measured for 200 trees by using the app Arboreal Træ (Arboreal Tree, n.d.). The app works by first walking close to the stem of the tree to mark the tree. Then we moved away from the tree about the same distance as the height of the tree while keeping the phone in an upright position and marking the base and the top of the tree. Then the application gives you the tree height displayed on the screen. The results are within a few percent.

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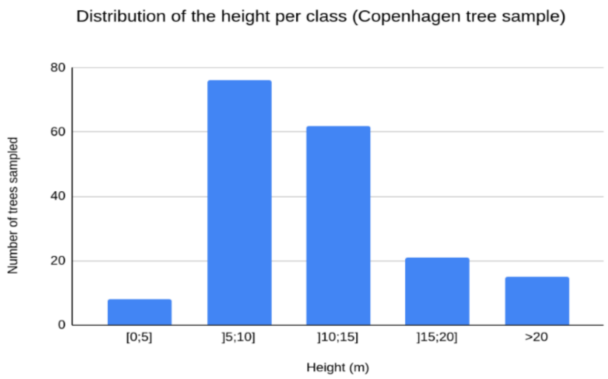

Figure 4.12 The distribution of height per class in the Copenhagen tree sample.

4.12 Tree physiological status (health status and percentage missing crown)

In the database *Kommunale traeer* for Copenhagen, tree health status data, labelled as "sundhed," is partially present but not complete nor up to date. Therefore, efforts were made during the project to calculate tree health for all trees in Copenhagen.

In **Copenhagen**, tree health status was determined using a Convolutional Neural Network (CNN) trained on photo interpretation of False Color Composites of RGBIr orthophotos of tree crowns in Brussels. The algorithm assigned scores ranging from 1 to 5, with each score representing a different level of vitality, from perfect health to near death. This trained algorithm was then applied to RGBIr summer orthophotos from 2017 in Copenhagen.

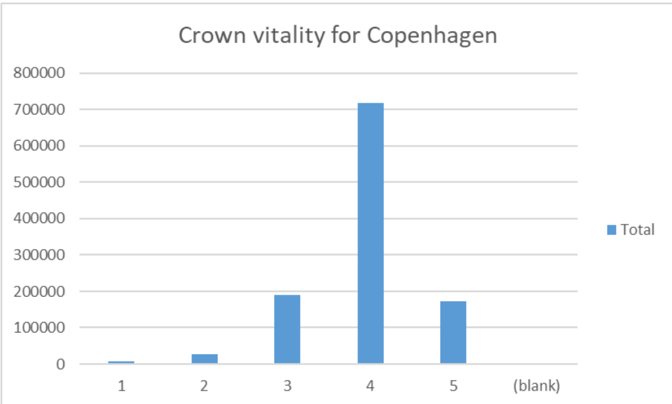

Figure 4.13 The distribution of crown vitality in the 100kTREEs Copenhagen tree map.

Similarly, for **Sofia**, a CNN was trained using photo interpretation of False Color Composites of RGB Orthophotos of tree crowns in Brussels. This trained algorithm was subsequently applied to RGB summer orthophotos from 2020 in Sofia.

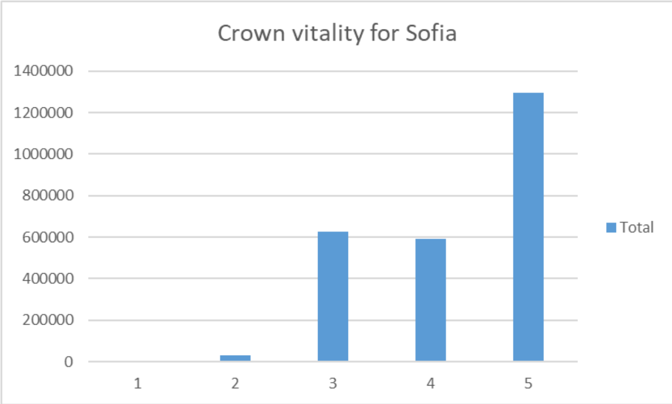

Figure 4.14 The distribution of crown vitality in the 100kTREEs Sofia tree map.

These tree health attributes were calculated per tree and added to the 100kTREEs datasets for Copenhagen (297.832 trees) and Sofia (630.898 trees).

The tree physiological status in the Copenhagen tree sample was assessed for the 200 trees by looking at how many percent of the crown was missing compared to how the tree would look in its natural form. The tree's health was determined by assessing how many percent of the tree crown was dead. Since the sampling period took place in winter, the absence of leaves on the trees made the assessment of tree health less accurate.

4.13 Tree planting date

This information was not present in the existing tree databases. It is very difficult, or even impossible to obtain accurate estimates, so this could not be delivered to WP4.

4.14 Tree species

In the Copenhagen tree sample, the tree species for the 200 trees were verified by looking at the tree trunk, tree appearance, texture, colour, and branches. Ideally, the sample would have been done in late spring to early autumn so the trees had leaves on but since the measurement could not wait, tree species had to be identified this way. The sample focused on 4 species and one variety: *Platanus x hispanica* (easy to identify by its spotty trunk), *Robinia pseudoacacia* (identified by thorns on branches and very grooved and scaly bark), *Sorbus intermedia* (identified by outer bark, buds, and twigs). Without the leaves it was sheer impossible to see the difference between *Tilia x europaea* and the variety *Tilia x europaea* 'Pallida'. A couple of the trees were not one of the five species. For those trees, a picture was taken, and the tree species were identified by appearance.

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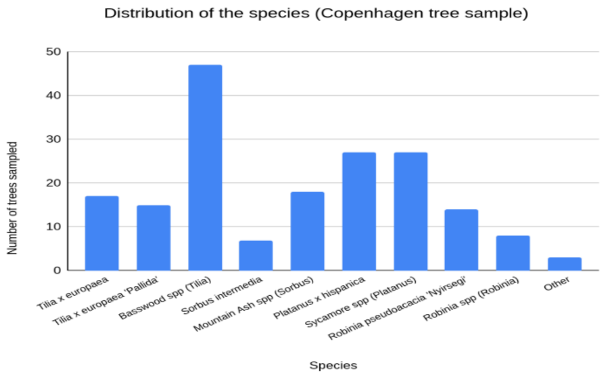

Figure 4.15 The distribution of species in the Copenhagen tree sample.

In the *Kommunale traeer* database, the tree species for 38.042 trees is documented in the column *traeart*. Due to the high number of misspellings, the list has been corrected before sharing it with WP4.

Species	Number
Tilia × europaea 'Pallida'	2496
Platanus × acerifolia	2409
Tilia europaea	2252
Robinia pseudoacacia 'Nyirsegi'	1193
Sorbus intermedia	1125
Quercus robur	1039
Aesculus hippocastanum	1014
Acer platanoides	845
Fraxinus excelsior	801
Salix sp.	751

Table 4-2. The 10 most frequent tree species in the Kommunale traeer *database.*

In the OneTree Initiative urban tree database, 5.291 trees have documented species names.

Species	Number
Salix alba	746
Juglans regia	444
Prunus cerasifera	436
Betula pendula	306
Fraxinus excelsior	276
Tilia cordata	194
Picea abies	180
Fraxinus oxycarpa	174
Quercus robur	163
Aesculus hippocastanum	156

Table 4-3. The 10 most frequent tree species in the OneTree Initiative urban tree database.

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5 Conclusions

The conclusions of deliverable 3.1, listing a set of tree attributes for modelling individual tree contributions to the ecosystem services (Vanwildemeersch et al., 2023), has been used as a solid foundation for the joint effort between work packages 2, 3 and 4 in obtaining the necessary data for constructing the tree and ecosystem models within WP4.

Indeed, the most interesting information has been extracted from 4 existing databases (the OneTree Initiative urban tree database, the Sofiaplan tree map, the database *Kommunale traeer* and the tree knowledge database) and prepared for use by WP4.

Furthermore, WP2 has supported data gap filling with LiDAR data analysis (for tree height and crown dimensions), with a regression model for extracting LAI from summer orthophotos and the LAI data, and with an algorithm for extracting tree vitality from summer orthophotos and the corresponding tree vitality data for both cities (task 2.3). This information has then been linked to the Sofiaplan tree map and to the newly produced Copenhagen tree map (task 2.2). The total number of trees in those combined databases comes close to one million!

An extra 200 trees, chosen strategically by WP4 throughout Copenhagen representing different growing conditions (location, sunlight, configuration), have been inventoried precisely by colleagues from CWare and EcoTree for providing extra information to WP4.

Soon, an extra database will be created, again by WP2, containing the NDVI data for both cities.

But some attributes were too difficult to encounter. It was impossible to find information on the budding and shedding of leaves (Phenological data), on the soil sealing percentage and on the tree planting date.

All the available information has been shared with the modelling specialists of WP4 through an FTP server.

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Attribute	Useful for modelling	Has been found in
Clearance height	Cooling effect	OneTree Initiative urban tree database, Copenhagen tree sample inventory
Crown diameter	Air pollution reduction, Cooling effect, Flood risk and estimated damages, Noise abatement	OneTree Initiative urban tree database, Sofiaplan tree map, Municipal tree database of Copenhagen, Copenhagen tree sample inventory
Crown form	Cooling effect	OneTree Initiative tree knowledge database
Diameter / circumference at breast height	Air pollution reduction, Biodiversity improvement, Cooling effect, Noise abatement, Potential carbon mitigation	OneTree Initiative urban tree database, Copenhagen tree sample inventory
Leaf Area Index (LAI)	Air pollution reduction, Cooling effect, Flood risk and estimated damages, Noise abatement	Copenhagen 100kTREEs tree map, Sofia 100kTREEs tree map
NDVI	?	This will be delivered in the future by WP2 to WP4
Phenological data	Air pollution reduction, Cooling effect, Flood risk and estimated damages, Noise abatement	OneTree Initiative tree knowledge database
Pruning regime	Biodiversity improvement, Cooling effect, Potential carbon mitigation	Copenhagen tree sample inventory
Soil sealing percentage (under trees)	?	Data on this subject has not been found.
Species specific transpiration	Cooling effect	Data on this subject has not been found.
Tree height	Air pollution reduction, Cooling effect, Noise abatement, Potential carbon mitigation	OneTree Initiative urban tree database, Copenhagen 100kTREEs tree map, Sofia 100kTREEs tree map, Copenhagen tree sample inventory
Tree physiological status (health status and percentage missing crown)	Air pollution reduction, Cooling effect, Potential carbon mitigation	Municipal tree database of Copenhagen, Copenhagen 100kTREEs tree map, Sofia 100kTREEs tree map, Copenhagen tree sample inventory
Tree planting date	Noise abatement, Potential carbon mitigation	Data on this subject has not been found.
Tree species	Air pollution reduction, Biodiversity improvement, Flood risk and estimated damages, Noise abatement, Potential carbon mitigation	OneTree Initiative urban tree database, Municipal tree database of Copenhagen, Copenhagen tree sample inventory

Table 5-1. The tree attributes proposed for modelling, the ecosystem services they are important to and the databases where information on them is found.

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6 References

Arboreal Tree (n.d.). Available at: https://www.arboreal.se/en/arboreal-tree-height-2/ (accessed 25 April 2024).

Copenhagen tree sample (2023). Available at: https://docs.google.com/spreadsheets/d/1PclQdBSG9aR1rE5KXA2Bo1X-tzBCOGxLxVYXl0glZoU/edit#gid=0.

DeepForest documentation website (n.d.). Available at: https://deepforest.readthedocs.io/en/latest/ (accessed 25 April 2024).

Eurosense (2023) Deliverable 2.3: Guidelines & tools urban tree mapping – Copenhagen tree dataset.

Eurosense (2024) Deliverable 2.3: Guidelines & tools urban tree mapping – Sofia tree dataset (extended version of the Sofiaplan tree map: https://sofiaplan.bg/portfolio/trees-index/).

Kommunale traeer (n.d.). Available at: https://www.opendata.dk/city-of-copenhagen/trae-basis-kommunale-traeer.

OneTree database (n.d.). Available at: https://ednodarvo.io/.

PocketLAI (2024). Available at: http://www.cassandralab.com/mobiles/1.

Trees index (n.d.). Available at: https://sofiaplan.bg/portfolio/trees-index/.

Vanwildemeersch, Pieter, Denti, Pablo, Petrov, Aleksandar, et al. (2023) Deliverable 3.1: Tree attributes version. 100kTREEs.

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DELIVERABLE REVIEW SHEET (DRS)

PROJECT:	100KTREES	**REVIEWER:** Hervé JEANJEAN	
DELIVERABLE REF:	3.1 – DR12	**VERSION**	1.0
DELIVERABLE TITLE:	Tree attributes final version	**DATE:**	07/06/2024
AUTHOR:	Pieter Vanwildemeersch, Aleksandar Petrov, Emma Dekeyser, Lea Piedigrossi, Emilie Kjaer Vinther		
FINAL RECOMMENDATION:	Modification required Y		

SHORT SUMMARY/COMMENTS

This deliverable is presenting the overall process for selecting tree attributes to be used for modelling ecosystem services. The document is of good quality and contains relevant information. The project partners are requested to address the minor remarks identified below, and to provide a global synoptic view of the selected attributes and links with ecosystem services similar to the figures presented at the mid-term review in Prague. Once these elements are corrected, the deliverable can be approved.

Additional comments:

Detailed comments

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed

(*) Possible Types are M / m / U / Q where M=Major, m=minor, U=Non compliance with contractual requirements and Q=Question.

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed
1.	2. Assessing the ecosystem services provided by trees through their attributes, page 12	m	NDVI, phenological data and soil sealing percentage under trees have beed added as new attributes: to which ecosystem services are they referring to?	Answer of the co-author: “NDVI is used in a variety of resources as a measure to monitor tree health. The initial idea was to include tree health status as an attribute which influences the tree growth model. According to the growth rate tree geometry (size) and (LAI) would have been determined. However, during the discussions the temporal resolution of this attribute was not sufficient to directly use it. We then relied on the Tree Vitality provided by project partners. For tree phenology and soil sealing percentage, the parameter would be usefull when physically modeling the individual trees. According to the study by Rotzer et al. 2019, they used these information for modelling the ecosystem services of individual trees on a monthly basis taking into account the soil-tree and leaf processes. Reference: https://doi.org/10.1016/j.scitotenv.2019.04.235” Addition in the deliverable by the author: “NDVI was considered particularly useful for monitoring tree health, which also influences tree growth rate (thus the temporal aspect of crown diameter and tree height). Phenological data was needed to include the seasonality of LAI in the model. Soil sealing within the crown projection was needed as an indicator of the environment’s growing potential for the tree, so to correct the growth model with information on the tree’s environment. ”	

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed
2.	3.7 The Copenhagen tree sample inventory, page 17	m	How are selected the 200 trees for having a good representation of the different situations? By random? stratified sampling?	Answer of the co-author: “The selection of 200 trees at the time of the project was reliant on the available datasets for two cities: (Copenhagen street trees data and Sofia tree dataset). To do so, we first identified the top 5 species (population) in the city of copenhagen according to the street trees;taking into account the names aligning with the Sofia dataset. This lead us to 5 classes of species which we allocated differentiated weight of sample size to those. Then for each species we chose random samples and then evaluated the sample groups by the large dataset to be representative.” Correction by the author to the deliverable: “200 trees were selected and mapped by WP4 according to different conditions of location, sunlight, configuration (tree alignments, groves etc.) to have a representative sample.” was replaced by: “Within the combined Sofia and Copenhagen datasets, the 5 most frequently occurring species were identified. Those species received subsequently a weight according to their importance in the original datasets. 200 trees were then randomly chosen in Copenhagen for extra measurements. The sample was evaluated to be representative by the large dataset (combining Sofia and Copenhagen data).”	

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed
3.	4.6 NDVI, page 24	m	NDVI derived from Sentinel-2 at 10m resolution is probably too coarse for monitoring trees in the cities. Have you tried VHR data at resolution below 1 m?	Indeed, the VHR data has been used. This was wrongly described in the text. The error was due to the fact that the NDVI calculations were not yet executed at the time of writing. The partner from WP2 that has written this part, has corrected it.	
4.	4.7 Phenological data, page 24	Q	The phenological attributes are varying with time, and thus should be monitored over time, within the vegetation cycle. This means that data should be collected with an adequate revisit frequency. How do you intend to proceed?	Answer of the co-author: “Indeed. Phenological data is time varying, yet here are studies which have developed empirical formulas for a certain tree species. The attribute is used in water cycle modelling and also the growth model itself (Following Rotzer et al. 2019). However, we did not proceed with the attributes as there were no measurements available. We rely on tree species specific values derived from literature and geometry for ES modelling.” No adaptations were done in the deliverable.	

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed
5.	4.10 Species specific transpiration, page 25	m	Can you provide more reference about the simpler model?	Answer of the co-author: "One of the models that considers trees in flood mitigation is **UFORE-Hydro (Wang et al. 2008).** The model uses species specific estimation of LAI and biomass for estimating the transpiration rate. However this model does not have spatial representation of flood and does not take into account the location of the tree. For this model a tree is represented by its LAI value. However, in our modelling process, the LAI for different species and also individual trees within the same species are differentiated according to their location and surrounding environment (Shade, geometry, light exposure). On a single tree level, the water balance module in the model by ROtzer (2019) - check previous references - uses the specific transpiration for calculating the water balance within the tree/ soil system. **(**Wang, Jun, Theodore A. Endreny, and David J. Nowak, 2008. Mechanistic Simulation of Tree Effects in an Urban Water Balance Model. Journal of the American Water Resources Association (JAWRA) 44(1):75-85. DOI: 10.1111/j.1752-1688.2007.00139.x)" As this explanation is highly *modelling*-centered and not so much *attribute*-centered, the current text has been kept without adaptation.	

Id.	Chapter / Page	Type (*)	Reviewer's comments and/or proposals	Author's response and agreed action	Approved / More information needed
6.	4.12 Tree physiological status, page 28	m	Can you elaborate on the magnitude of the error resulting from the fact that the sampling took place in winter?	Usually, the estimation of the percentage of missing crown is done in summertime (with leaves). When this is done in winter time, it depends strongly on the experience and expertise of the person doing the diagnostic. Sadly, it is not possible to estimate the magnitude of error and no scientific literature has been found on this subject.	
7.	5. Conclusions, page 30	M	A summary table of attributes to be assessed should be presented in the conclusions. At the mid-term review, a nice figure has been presented, explaining which attributes have been discarded and which ones maintained for modelling purposes and for display purposes. Please use a similar figure in the deliverable, with the corresponding ecosystem services to be retrieved.	I have added the table below the conclusions as proposed. Thanks for mentioning that our figure was nice, but we prefer not putting it into our deliverable, as the information shown in the figures of the presentation, is already present in the deliverable (table 2-1, table 2-2, and now also table 5-1)	