



The ecosystem disservices of trees on sidewalks: A study based on a municipality urban tree inventory in Central Italy

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ABSTRACT

Urban green infrastructure, including street trees, plays a key role in providing ecosystem services to urban residents. However, to fully understand the effective role of trees in the urban context, it is also necessary to evaluate the disservices that they can produce in the development of their functions if not managed in an adequate and integrated way. This contribution aims to demonstrate an approach to assess three disservices (pavement damage, aesthetic damage, likelihood of tree failure) of street trees at the municipal level, starting from the existing municipal tree inventory. In this case study, from the street tree population, a sample of approximately 5% of the trees was drawn by stratified random sampling, where the strata were composed of groups of tree species. In particular, a sampling scheme is adapted in which the probability to select a tree in the sample is greater for bigger trees, under the assumption that the bigger the trees the greater are the disservices caused. In this way, a greater precision of the estimates of the considered disservices for the population of urban trees is expected. The results show a high variability of disservices provision among species groups. The results also confirmed a positive correlation between the considered disservices and tree diameter at breast height, while other tree attributes such as total height and crown diameter were found to be positively related only to pavement damages. Finally, severe pruning can lead to a high level of the aesthetic and functional disservices even for shorter and younger street trees.

1. Introduction

Urban green infrastructure includes urban woodlands, parks, tree rows and single trees. Within urban ecosystems, green infrastructure where tree species predominate play a key role in improving the economic, aesthetic (Escobedo et al., 2015; Li et al., 2015; Vandermeulen et al., 2011), cultural (Andersson et al., 2015; Bertram and Rehdanz, 2015) and architectural assets (Tyrväinen et al., 2005) and the overall quality of life of urban residents, so much so that they are considered fundamental nature-based solutions to improve sustainability in urban contexts (Frantzeskaki, 2019; Maes and Jacobs, 2017; Tomao et al., 2017). Ecosystem services (ES) generated from urban trees include relevant regulating services (MEA, 2005) such as the improvement of air quality (Escobedo et al., 2015; Nowak et al., 2006), local cooling through shading and evapotranspiration (Pace et al., 2021; Speak et al.,

2020; Upreti et al., 2017) and reduced rainfall runoff (Livesley et al., 2014). Many studies also report the provision of cultural services such as the positive effects on human health and wellbeing (Carrus et al., 2015; Laforteza et al., 2009; Nesbitt et al., 2017; Speak et al., 2021; Tomao et al., 2018, 2016).

However, different urban tree species do not provide the same ES to the same magnitude and ES do not benefit all urban residents equally (Quatrini et al., 2019; Speak et al., 2018). Furthermore, the implementation of successful urban greening initiatives has several obstacles to overcome. For example, there is often a shortage of available land in cities and trees often survive in stressful environments (Salmond et al., 2016). Moreover, in the development of their functions, if not managed in an adequate and integrated way, trees sometimes can negatively affect the quality of the environment or the life of urban residents, producing some of the so-called ecosystem disservices (Lyytimäki, 2015;

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Roman et al., 2021).

Urban ecosystem disservices (ED) can be defined as ecosystem-generated functions, processes and attributes that result in perceived or actual negative impacts on human wellbeing (Shackleton et al., 2016, 2015). Examples are (i) the production of allergy-inducing pollen (Cariñanos et al., 2017, 2016), (ii) the emission by trees of biological volatile organic compounds (BVOC) which can be the precursor to tropospheric ozone pollution in cities with consequent negative respiratory effects (Calfapietra et al., 2013), (iii) risk of damage to people or grey infrastructure due to tree failure (Portoghesi et al., 2023; Tomao et al., 2015).

Based on these premises, urban planning should have a broader consideration of urban trees for public policy and sustainability, requiring a balanced understanding of ES and ED (Lyytimäki, 2015; Prigioniero et al., 2022). Ordóñez Barona et al. (2022) highlight that most scientific literature focuses on studying how people perceive the positive aspects of urban trees while the negative aspects of trees (i.e. disservices) and their costs are less studied in urban forest research (Kirkpatrick et al., 2012; Lyytimäki, 2017; Roman et al., 2021; Shackleton et al., 2015).

There has been growing interest in municipal tree inventories in recent decades, especially in North America and Europe, where municipalities have increasingly performed them (Keller and Konijnendijk, 2012; Sjöman et al., 2012). Municipal tree inventories in North America have largely involved the use of the i-Tree software to perform economic valuations of urban trees (Östberg et al., 2018; Rogers et al., 2017), while Northern Europe has focused more on management issues, e.g. tree health and monitoring of tree stand dynamics (Keller and Konijnendijk, 2012; Östberg et al., 2018). In Mediterranean Europe, urban tree inventories mainly concentrated on assessing crown volumes, tree growth, wood formation, biodiversity and ES (Krajter Ostoić et al., 2018). In Italy, the Law No. 10/2013 ("Regulation for the development of urban green areas") provides that Italian municipalities with a population of more than 15,000 inhabitants have an inventory of trees located in public green areas. The inventories are organised on three levels. The first level is mandatory for all municipalities and includes information on the quantity, location and size of urban public green areas. The second level inventory is mandatory for municipalities with more than 15,000 inhabitants and includes information on trees (genus, species, tree size and health) present in the areas identified by the first-level inventory. The third level inventory is not mandatory and includes details on shrubs, herbaceous covers and facilities of urban green areas (Rossi et al., 2022).

In Italy, urban tree inventories are quite widespread: over 90% of provincial capitals have first-level inventories, while 80% have completed or ongoing second-level inventories (Rossi et al., 2022), which can be considered censuses since all trees are usually measured. However, estimates of ES and ED per tree are rarely included in such inventories. For these attributes, on the other hand, mean and total values can be estimated at the municipality level (and/or subdivisions into subareas of the municipality and/or of types of green infrastructure, such as trees in gardens or roadside trees) by selecting a sample of trees from the census carried out: the sampling design can exploit the information provided by existing inventories to stratify the sample, thus increasing the effectiveness of statistical estimation (Ma et al., 2021).

Keeping these considerations in mind, the present work aims to demonstrate an approach for the evaluation of three ED (pavement damage, aesthetic damage, likelihood of tree failure) from urban street trees at the municipal level starting from the urban tree inventory of the city of Viterbo (Central Italy). In particular, we used a stratified sampling scheme where within each stratum the probability of a tree being selected is higher for larger trees, under the assumption that the bigger the trees the greater the ED caused (Speak et al., 2022). In this way, greater precision of the unbiased estimates of average or total values is expected for the considered population of urban trees, as emphasized in most sampling textbooks (e.g., Hedayat and Sinha, 1991, Section 5).

2. Materials and methods

2.1. Description of the study area

The study was conducted in the municipality of Viterbo, Central Italy (Fig. 1). The city has a population of 65,949 inhabitants (National Institute of Statistics (ISTAT), 2022). The municipal territory covers about 40,000 ha and is mainly composed by agricultural areas (about 29,000 ha) and forests (about 9000 ha). The urban area (city) extends over 2000 ha, of which 1.5% is represented by green areas larger than 1 ha (Lazio region, 2018). The spatial pattern of the urban forest shows differences between the historical centre of the city, where most of the trees grow in private gardens and squares, and the urban fringe, where most of the trees are found in public or private green areas and along streets.

The climate is classified as warm-summer Mediterranean climate (Csa) by Köppen-Geiger climate classification (Peel et al., 2007). The mean annual temperature is 13.6 °C and the annual rainfall varies from 775 to 869 mm, of which 135 in summer (Tomao et al., 2015). In our study area, the average PM10 from 2015 to 2021 was 17.8 µg m⁻³ and the main sources of particulate matter are heating and traffic (ARPA-LAZIO, 2023). In particular, vehicular traffic is mainly concentrated along the streets immediately outside the city centre and on the main road axes that connect Viterbo with the neighbouring towns, while it is less intense in the fringe areas.

2.2. Data source

Urban tree inventory data collected in Viterbo city during late spring/early summer of 2020 are considered here. As is the case for most cities, the inventory was primarily conducted to assess tree health and the consequent risk of falling trees. In addition to species and stem diameter at breast height (DBH), a visual assessment of health status was performed for each tree.

A total of 2646 trees were censused, most of which (47%) are *Tilia platyphyllos* Scop. and *Platanus acerifolia* (Aiton) Willd. (12%). The trees belong to different types of green infrastructure (i.e. urban forest components, *sensu* FAO, 2016), as shown in Table 1. For the purposes of this study, the largest group was considered, i.e. trees labelled as street trees.

2.3. Sample selection

The data collected from the urban forest inventory (tree species, DBH and state of health) are insufficient to assess both tree ES and ED. Therefore, the data were integrated with a further field survey carried out on a sample of trees. We chose the sample size of 100 trees based on available budget for additional ED evaluation.

Let U denote the population of $N = 1769$ street trees. We have divided U into strata determined by tree species: 9 strata were determined by the species that have more than 30 trees, while the species that have fewer than 30 trees were grouped into two miscellaneous strata indicated with "Other broad-leaved" and "Other conifers", composed respectively of 118 and 30 trees, for a total of 11 strata. We indicate the strata with U_1, \dots, U_{11} and the strata sizes with N_1, \dots, N_{11} (Table 2). For each tree $j \in U$ the DBH x_j was available from the complete survey (census) of the population.

Sample S of $n = 100$ trees (about 5% of N) was selected by a stratified sampling scheme where trees were selected within strata with probabilities proportional to x_j according to the so called PPS sampling (e.g., Hedayat and Sinha, 1991, Section 5). We first determined the number of trees to be selected within each stratum proportionally to the stratum size: n_l^* is the nearest integer to nw_l , where $w_l = N_l/N$ denotes the stratum weight ($l = 1, \dots, 11$). Then we adjusted the n_l^* s to avoid sample sizes of 2 or 3 individuals that would degrade variance estimation. We indicate with n_1, \dots, n_{11} the final sizes of the sample in each stratum.

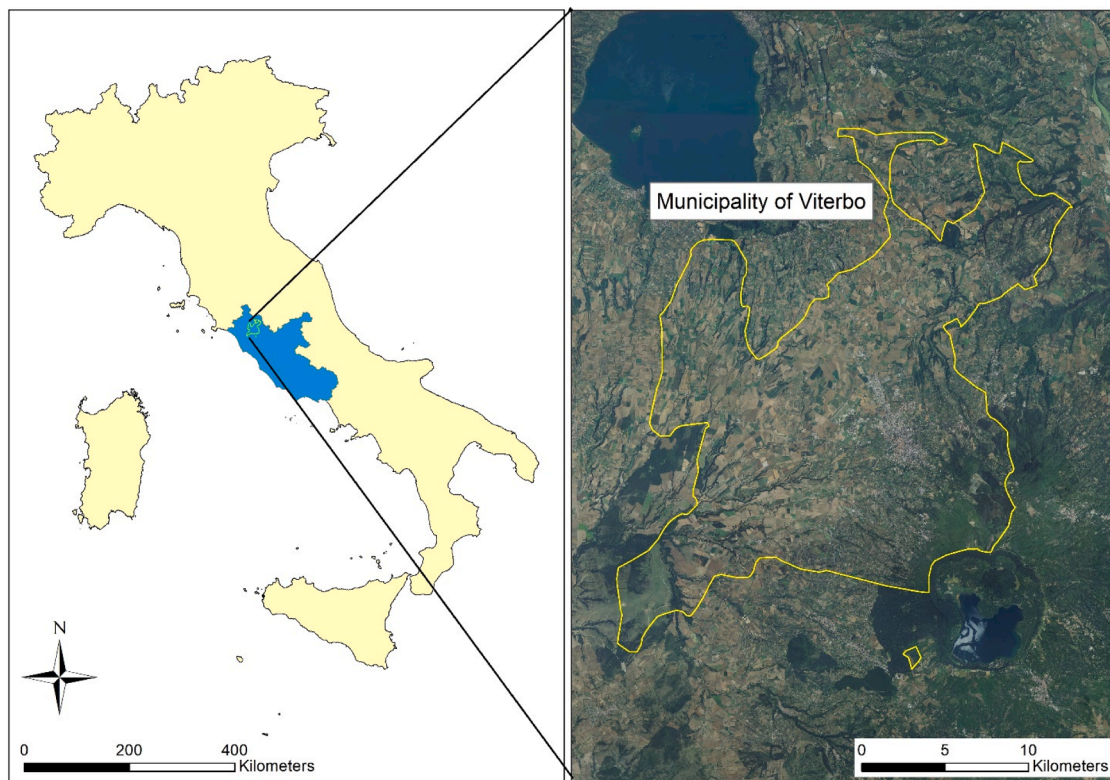


Fig. 1. The municipality boundaries (in yellow) of Viterbo (Lazio region, Central Italy).

Table 1

Number of trees by urban forest type included in the urban forest inventory of the municipality of Viterbo.

Urban forest type	Number of trees
Trees on streets	1769
Trees in public squares	151
Trees in parking areas	200
Parks and gardens	399
Other green spaces (sports grounds, industrial areas)	127
Total urban trees	2346

Finally, from each stratum l we selected a sample S_l of size n_l adopting the IIPS [Sampford \(1967\)](#) scheme which ensured first order inclusion probabilities proportional to the x_j s, i.e.,

$$\pi_j = \frac{n_l x_j}{T_{xl}} \quad j \in U_l \quad (1)$$

where T_{xl} indicates the total of x_j s within stratum l ($l = 1, \dots, 11$). As for the second order inclusion probabilities π_{jh} for each pair $h > j \in U_l$, they have a very huge expression not reported here for brevity (see [Chaudhuri and Vos, 1988](#), section 5.19).

2.4. Survey variables

The field survey was conducted on the 100 trees selected as described in §2.3 in the months of June and July 2021. The selected trees were detected in the field according to a unique identity code reported on a label placed on the stems of the trees during the municipal inventory. Dendrometric data including total height and crown diameter were measured using an electronic hypsometer/rangefinder (Vertex IV, Hagl f Sweden, L ngsele, Sweden). Tree biomass was calculated using the allometric equations of [Tabacchi et al. \(2011\)](#). Furthermore, for each tree, the presence/absence (1/0) of structural defects and damages in

Table 2

Number of trees by species groups, defined based on the number of street trees belonging to each species in the municipality of Viterbo.

Species groups (Stratum U_l)	Scientific species names	N_l	n_l^*	n_l
American Maple	<i>Acer negundo</i> L.	31	2	4
Cherry Plum	<i>Prunus cerasifera</i> var. <i>Pissardii</i>	54	3	5
Downy oak	<i>Quercus pubescens</i> L.	31	2	4
Hawthorn	<i>Crataegus laevigata</i> (Poir.) DC.	87	5	5
Judas tree	<i>Cercis siliquastrum</i> L.	61	3	5
Large-leaved linden	<i>Tilia platyphyllos</i> Scop.	1019	58	46
Plane tree	<i>Platanus acerifolia</i> (Aiton) Willd.	240	14	14
Siberian elm	<i>Ulmus pumila</i> L.	44	2	4
Mediterranean Stone pine	<i>Pinus pinea</i> L.	54	3	5
Sub-total		1621	92	92
Other broad-leaved	<i>Acer campestre</i> L.; <i>Acer platanoides</i> L.; <i>Ailanthus altissima</i> L.; <i>Laurus nobilis</i> L.; <i>Crataegus azarolus</i> L.; <i>Crataegus crus-galli</i> L.; <i>Morus nigra</i> L.; <i>Quercus ilex</i> L.; <i>Ligustrum lucidum</i> W.T. Aiton; <i>Populus nigra</i> L.; <i>Quercus rubra</i> L.; <i>Robinia pseudoacacia</i> L.; <i>Styphnolobium japonicum</i> (L.) Schott	118	7	4
Other Conifers	<i>Cupressus sempervirens</i> L.; <i>Cedrus atlantica</i> (Endl.) Manetti ex Carrière; <i>Cedrus deodara</i> Roxb. ex (D.Don) G. Don; <i>Picea abies</i> (L.) H. Karst.	30	2	4
Total		1769	101	100

root-collar, stem and crown (e.g. strangling roots, decays), the interaction with artefacts, and the arboriculture interventions (e.g. pruning, pollarding, see Appendix A for the complete list) were recorded, which allowed the considered ED to be estimated according to the literature ([Jahani, 2019](#); [Jim and Zhang, 2013](#); [Kane, 2008](#); [Klein et al., 2020](#); [Mattheck and Breloer, 1994](#); [Pokorny, 1992](#); [Smiley et al., 2012](#); [Terho](#)

and Hallaksela, 2005; Tomao et al., 2015). In the case of aesthetic damage, we recorded all those characteristics that could decrease the aesthetic appreciation of natural vegetation structure, shape, foliage pattern (e.g. damages to the crown structure) (Avolio et al., 2015; Smardon, 1988; Theodorou et al., 2022). In addition, indicators describing whether or not the urban tree has been well-cared for (e.g., presence of sprouts restricting passage or mechanical damage to the stem) were also included (Mundher et al., 2022a, 2022b; Theodorou et al., 2022).

Table 3 and Appendix A report the complete list of indicators adopted to describe each ED.

The value of each ED for each tree was determined by summing the values (0, 1) of the relevant indicators for that ED, and scaling the resulting sum between 0 and 1 by min-max normalization, as proposed by Speak et al. (2018).

2.5. ED and dendrometric attributes estimation

Attributes of interest were: tree height (m), crown diameter (m), tree biomass (kg), and the three ED considered (i.e. pavement damage, aesthetical damage, likelihood of failure, normalized in the interval 0–1 as described in §2.4). We recorded these six attributes on each selected tree. We indicate with y_{kj} the value of the k -th attribute in unit j ($k = 1, \dots, 6$). The quantities under estimation were

$$T_{kl} = \sum_{j \in U_l} y_{kj} \quad (2)$$

and $\bar{Y}_{kl} = T_{kl}/N_l$, i.e. the total and the mean of the k -th variable in the stratum l ($k = 1, \dots, 6$; $l = 1, \dots, 11$) and

$$T_k = \sum_{l=1}^{11} T_{kl} \quad (3)$$

and $\bar{Y}_k = T_k/N$, i.e. the total and the mean of the k -th variable in the whole population ($k = 1, \dots, 6$).

Based on sample data we estimated these unknown quantities using the Horvitz-Thompson (HT) estimators

$$\hat{T}_{kl} = \sum_{j \in S_l} \frac{y_{kj}}{\pi_j} = \frac{T_{kl}}{n_l} \sum_{j \in S_l} \frac{y_{kj}}{x_j} \quad (4)$$

$$\hat{\bar{Y}}_{kl} = \hat{T}_{kl}/N_l \quad (5)$$

$$\hat{T}_k = \sum_{l=1}^{11} \hat{T}_{kl} \quad (6)$$

$$\hat{\bar{Y}}_k = \hat{T}_k/N \quad (7)$$

We estimated the variances of these estimators using the Sen-Yates-Grundy variance estimators (e.g., Hedayat and Sinha, 1991, Section 3.1)

$$\hat{V}(\hat{T}_{kl}) = \sum_{h > j \in S_l} \frac{\pi_j \pi_h - \pi_{jh}}{\pi_{jh}} \left(\frac{y_{kj}}{\pi_j} - \frac{y_{kh}}{\pi_h} \right)^2 \quad (8)$$

$$\hat{V}(\hat{\bar{Y}}_{kl}) = \hat{V}(\hat{T}_{kl})/N_l^2 \quad (9)$$

Table 3
Urban ecosystem disservices evaluated in this study.

Ecosystem disservices	Number of Indicators	Range
Pavement damage	4	0–1
Aesthetic damage	32	0–1
Likelihood of tree failure	17	0–1

$$\hat{V}(\hat{T}_k) = \sum_{l=1}^{11} \hat{V}(\hat{T}_{kl}) \quad (10)$$

$$\hat{V}(\hat{\bar{Y}}_k) = \hat{V}(\hat{T}_k)/N^2 \quad (11)$$

Finally, we obtained the standard error (SE) estimates from the square roots of the variance estimates and the relative standard error (RSE) estimates from the ratios of the SE estimates to the total or the mean HT estimates.

Furthermore, based on sample data, we estimated pair-wise Pearson correlation coefficients between the three ED and dendrometric attributes. Estimating correlation coefficients was less standard than estimating totals and means and required approximation of the variances from which the estimates of the variances were obtained (see Appendix B). From the resulting correlation estimates and their standard error estimates, we then tested the hypothesis of null correlations by the familiar t-test (see Appendix B).

3. Results

3.1. Assessment of dendrometric attributes

The main dendrometric attributes of the species groups are shown in Table 4. The DBH statistics are derived from the census of the entire street tree population, while the mean total height, crown diameter and tree biomass are estimated from the sample survey described at § 2.3.

The street trees population shows an average DBH greater than 38 cm, an average height of about 13 m and an average crown diameter of about 7 m. The species with largest size are Downy oak, Mediterranean Stone pine and Siberian elm, with an average DBH greater than 50 cm. The Mediterranean Stone pine also shows high values of tree height and crown diameter. Oaks, as well as linden, plane trees and elms, resulted systematically damaged by severe pruning, as shown by percentages of pollarded trees greater than 60% (see Appendix C). This practice has resulted in shorter trees with limited height and crown size. The smallest trees belong to those species usually found in nature as shrubs or small trees such as the Hawthorn or the Judas tree.

3.2. Assessment of ED

The estimates for the three ED considered are shown in Table 5, while Fig. 2 reports three examples of trees characterized by high levels of the considered ED.

The average value of street tree disservices for the municipality of Viterbo ranges from 0.23 (RSE=8.3%) to 0.26 (RSE=12.7%), highlighting how, on average, trees show the presence of one-fourth of the indicators of the ED selected in the case study. However, different considerations arise at the level of species groups.

Conifers show lower values of both aesthetic damages and likelihood of failure. In the case of damages to the pavement, Mediterranean Stone pine is the species causing the major disservices with a value of 0.88 (RSE=18.7%). Broadleaved species show higher values for aesthetic damage and likelihood of failure. Oaks, elms, and maples have a value for these two disservices greater than (or equal to) 0.3. Among broadleaved species, *Platanus acerifolia* causes the most damage to road and sidewalks average value = 0.43, RSE= 20.9%). The broadleaved species that on average provide lower disservices is Judas tree, showing ED values lower than 0.16 (RSE=37.5%).

3.3. Correlation analysis

The correlation analysis (Table 6) between the main dendrometric attributes and the selected disservices shows that larger trees are associated with higher disservices. All ED considered are positively correlated to DBH ($p < 0.01$ for pavement damage and $p < 0.1$ for aesthetic

Table 4

Mean values of the main dendrometric attributes of the species groups selected in the study. Statistics for DBH are calculated on the entire population (i.e., the official urban tree inventory of the municipality of Viterbo), while statistics for height, crown diameter and tree biomass are estimated by the sample survey. CV = percent coefficient of variation; RSE = percent relative standard error.

Species	tree diameter at breast height (cm)	CV	tree height (m)	RSE	tree crown diameter (m)	RSE	tree biomass (kg)	RSE
American maple	29.8	29.9	7.5	21.6	4.7	12.2	135.1	24.1
Cherry plum	15.2	48.5	5.6	17.0	5.8	23.3	38.0	15.4
Downy oak	55.4	32.4	8.5	7.0	7.7	8.4	1242.1	10.0
Hawthorn	14.5	37.1	5.8	11.4	3.7	28.8	32.7	8.0
Judas tree	16.8	55.4	7.9	10.1	4.5	15.7	42.9	9.5
Large-leaved linden	40.1	43.5	14.0	5.3	7.6	6.5	274.2	5.0
Other broad-leaved	29.1	74.6	10.6	11.6	5.0	26.5	203.9	35.0
Other Conifer	42.9	49.2	10.6	9.5	5.3	22.1	676.2	17.4
Plane tree	45.7	35.0	15.8	6.3	8.4	7.2	380.8	7.3
Siberian elm	59.8	27.4	13.0	14.1	8.3	17.2	578.6	15.4
Mediterranean Stone pine	69.9	19.2	17.6	2.2	13.1	2.2	1626.6	12.5
Urban trees in the municipality of Viterbo	38.9	51.3	13.0	3.6	7.3	4.4	327.1	3.8

Table 5

Mean values estimated for the three ED considered in this study. RSE = percent relative standard error.

Species	pavement damage	RSE	aesthetic damage	RSE	likelihood of tree failure	RSE
American maple	0.15	94.0	0.38	35.8	0.36	33.9
Cherry plum	0.06	88.3	0.24	45.0	0.26	33.8
Downy oak	0.12	92.5	0.33	12.1	0.32	24.7
Hawthorn	0.00	-	0.27	57.8	0.25	66.0
Judas tree	0.00	-	0.16	37.5	0.15	30.0
Large-leaved linden	0.25	18.8	0.22	6.8	0.21	7.1
Other broad-leaved	0.31	59.4	0.34	61.2	0.29	74.1
Other Conifer	0.00	-	0.03	33.3	0.07	32.9
Plane tree	0.43	20.9	0.23	9.6	0.29	13.8
Siberian elm	0.06	86.7	0.29	21.0	0.34	14.4
Mediterranean Stone pine	0.88	18.6	0.29	6.9	0.14	5.0
Urban trees in the municipality of Viterbo	0.26	12.7	0.23	8.3	0.23	8.7

damage and risk of failure). Furthermore, damages to pavement and aesthetic damage are also positively associated with tree biomass ($p < 0.01$ and $p < 0.05$, respectively).

Tree height and crown diameter are positively correlated to the damage to the pavement ($p < 0.01$) but not to the aesthetic damage and the likelihood of tree failure. The close relationship between loss of aesthetic value and likelihood of failure is also confirmed by the strong positive correlation between the two ED (correlation coefficient = 0.89, $p < 0.01$).

4. Discussion

Much attention has recently been paid to the positive effects of trees in the urban context on people's well-being (Carrus et al., 2015; Dickinson and Hobbs, 2017; Dobbs et al., 2019; Sang et al., 2021), while there is still a lack knowledge on the potential disservices caused by urban trees (Portoghesi et al., 2023; Roman et al., 2021).

The results of this case study, which can be transferred to many other cities under similar conditions, show how different species (or group of species) can provide very different levels of ED. Broadleaved species have shown a worse status of health resulting in greater aesthetic damage and probability of failure. In the case of downy oak and elm, this evidence can be explained by the size (average DBH > 55 cm), and therefore the age of the sampled trees, while for the American maple

(average DBH < 30 cm) pruning often caused considerable damages to the canopy structure, compromising the vitality of many trees and favouring early senescence (Sanders et al., 2013). High levels of pavement damages were also found for *Platanus acerifolia*: roadside plane trees typically grow in pavement cutouts (the so-called tree pits), which are known to cause significant conflicts when space is no longer sufficient for tree growth (Sanders et al., 2013). Only broadleaved species of smaller size and slower growth, compared to other urban trees (e.g. Judas tree), provide lower disservices on average, as these characteristics allow less invasive management and consequently less stress on trees.

Conversely, conifers, probably due to a better state of health status and less frequent pruning (see Appendix C), provide less ED in our case study. An exception is the very high level pavement damages provided by *Pinus pinea*. In fact, the horizontal roots of Mediterranean Stone pine, when exposed to the pressure of vehicular traffic, are typically forced to move between the soil and the road surface, thus breaking the pavement (Caneva et al., 2020).

Our results show how disservices are distributed unevenly along streets at the municipality level. Similar results are provided by von Döhren and Haase (2019), who demonstrated how differences in tree composition influence the distribution of ED in Berlin districts. This difference between species with respect to ED is also known for other disservices not considered by this study such as the emission of BVOC (Calfapietra et al., 2013) or the emission of pollen and its allergenicity (Cariñanos et al., 2019, 2016). The uneven distribution of disservices was also reported by a subsequent article by von Döhren and Haase (2022), who found that specific disservices are related to potentially vulnerable targets. Thus, a possible improvement in urban planning research would be to use the available geospatial data to explore the spatial distribution of ES and ED (Baines et al., 2020; Barbierato et al., 2020; Li et al., 2019).

The ED considered by this study proved to be positively correlated with tree size (DBH), thus confirming the initial hypothesis that the bigger the trees the more ED are caused. This evidence is in line with the finding of Speak et al. (2022), who observed a positive correlation between tree size and ED. However, total height and crown diameter were not significantly correlated to aesthetic damage and risk of failure. This counterintuitive result can be explained by the severe pruning of many species early after planting. This has reduced tree height and damaged the crown structure, causing premature senescence (Suchocka et al., 2021) and, therefore, high level of disservices even for shorter street trees.

This study focused on the disservices provided by a specific category of urban trees, i.e. street trees, which differ significantly in terms of management needs and growth conditions compared to other urban tree components (Smith et al., 2019). Street trees usually grow in limited spaces, which in turn reduces the maximum size trees can reach



Fig. 2. Three examples of sampled trees characterised by high level of the considered disservices. A) A conifer tree (*Cedrus atlantica*) that caused relevant damages to the curb and the pavement. B) A young, but senescent, cherry plum (*Prunus cerasifera*) with multiple defects affecting aesthetic value (e.g. discontinuous crown with residuals of cutted tree branches, wounds/mechanical damages, dead branches). C) An adult Mediterranean Stone pine (*Pinus pinea*) with a high likelihood of failure due to a combination of damages to roots, leaning stem and asymmetric crown.

Table 6

Correlation analysis between the main dendrometric attributes and selected disservices based on Pearson's correlation coefficient estimates. Level of significance: * $p < 0.10$; ** $p < 0.05$, *** $p < 0.01$.

	Diameter at breast height	Total height	Crown diameter	Tree biomass	Pavement damage	Aesthetic damage	Likelihood of tree failure
Diameter at breast height	1						
Total height	0.680***	1					
Crown diameter	0.589***	0.369	1				
Tree biomass	0.841***	0.626***	0.720***	1			
Pavement damage	0.311***	0.400***	0.432***	0.267***	1		
Aesthetic damage	0.226*	-0.108	-0.109	0.176**	0.100	1	
Likelihood of tree failure	0.216*	-0.042	-0.160	0.116	-0.101	0.894***	1

(Sanders et al., 2013; Smith et al., 2019). The high level of stress, due to the limited space available, frequent pruning and damages from car traffic, can cause significant early senescence (Smith et al., 2019). This raises the issue of early tree removal and replacement. In conventional forest management, cutting occasions are chosen based on the time needed to reach a targeted size (or age) according to the species potential (Sanders et al., 2013). However, in the urban context, the maximum age that trees can reach is much lower than in natural conditions and maturity is expected earlier.

This suggests that specific urban forest management instructions addressing this issue are needed to limit ED and to have a continuous provision of ES by street trees. In Italy, these instructions are not mandatory, even if many municipalities adopted a regulatory tool for public green spaces, and also included the urban forest management plan as part of the city masterplan.

In this perspective a useful tool would be to identify a maximum size

(or age) per species and type of green infrastructure, after which trees should be replaced (Sanders et al., 2013). The plan should also include a list of those trees which, despite exceeding the maximum size, should be maintained due to their exceptional cultural or monumental value (Asciuto et al., 2015; Cannizzaro and Corinto, 2014; Ciaffi et al., 2022, 2018). This planning tool would also help avoid even-aged tree populations where all trees reach relative maturity at the same time, thus potentially causing entire portions of urban trees to be removed at once.

Another result of this study is the positive correlation between the likelihood of tree failure and the reduction of the aesthetic function. This evidence confirms the close relationship between disservices and the perception of them by the inhabitants (Koyata et al., 2021; Theodorou et al., 2022). This perception can vary by site, people's age, culture and environmental and social factors (Brown et al., 2020). Although several studies have shown that the ED by street trees are perceived as very limited, especially when compared to the ES offer (Koyata et al., 2021;

Tian et al., 2020), awareness of the negative effects of street trees on quality of life is increasing (Delshammar et al., 2015; Portoghesi et al., 2023; Roman et al., 2021; Theodorou et al., 2022). Therefore, decision-making on urban forestry should increasingly take into account disservices to avoid indirect and unintended negative consequences and costs for communities (Roman et al., 2021).

From a methodological point of view, urban tree inventories can be exploited as a basic tool on which precise evaluation of ED can be obtained at reasonable costs. Tree species and DBH are two pieces of information provided by almost all urban tree inventories and can serve as a basis for planning sample surveys aimed at assessing further dendrometric attributes and ES/ED characteristics not measurable on the entire tree population due to high survey costs.

The estimation strategy adopted here has multiple applications, and not only related to disservices. The assessment of biomass (and carbon) stocked in urban trees is one of the direct results of our approach and can be used for the assessment of ES. Furthermore, other quantitative indicators can be estimated, based on dendrometric attributes. In this regard, available models for pollutant removal assessment such as AirTree (Fares et al., 2020, 2019), which require the information on tree stem size and crowns by species as estimated by our approach, can be applied. Another possible application is the assessment of the monetary value of urban trees. Indeed, the estimation of this value is rarely reported by urban forest inventories due to the high cost of the surveys needed to evaluate it: the sampling approach proposed here can significantly reduce this cost, thus supporting an evidence-based decision-making process by urban managers (Corona, 2018).

We have focused the case study in the estimation of the ED based on the presence/absence of specific indicators with the main objective of demonstrating the feasibility of our methodological approach, but it also possible to estimate quantitative ED such as emissions of BVOC or pollen allergenicity (Calfapietra et al., 2013; Cariñanos et al., 2016). The use of the re-scaling approach can be then applied to compare them, regardless of the unit of measure (Speak et al., 2022).

The indicators selected here reflect the biophysical attributes related to the respective ED, but additional indicators could be chosen. For example, likelihood of tree failure is a broad category and other tree defects can be added: the proposed strategy is flexible enough to be adapted to other contexts that require specific additional indicators to have a reliable failure risk assessment. A possible further improvement would be the consideration of potential targets (Tomao et al., 2015; von Döhren and Haase, 2019). Weighting the contributions of individual indicators would also be a further step, although other studies have shown that different weighting systems can lead to the same results as those obtained by an equally-weighting approach (Tomao et al., 2015). An interesting development would also be to use tree characteristics (e. g. tree shape, crown shape, root type) instead of species to stratify the sampling.

5. Conclusions

The proposed approach implements a quantitative assessment of three municipal-level ED based on a sample of street trees selected from the urban tree inventory of the city of Viterbo. The proposed ED assessment represents a pilot study that can be easily replicated to other cities where such inventories are available. The number of urban tree inventories in Italian municipalities as well as in other European cities is expected to increase, expanding the potential sites where the methodology can be replicated. Applications of the approach to different contexts can elucidate ED provision by urban trees, thereby improving knowledge on the possible trade-offs between ES and ED provision in urban environments, with particular reference to the space available for tree rows, to their sustainable management and to the criteria for their replacement at the end of their life cycle.

ED estimation is rarely reported in urban forest assessment and carries a higher cost of the field surveys, especially in medium-sized and

large cities. The sampling approach proposed here can provide reliable ED estimates at significantly reduced cost, since the indicators needed to evaluate them are collected on only a small portion of municipal trees.

Our hypothesis that the larger the trees the more ED caused was confirmed, all ED being significantly related to tree size. However, tree attributes such as tree height and crown diameter were found to correlate only with pavement damage, suggesting that severe pruning results in a high level of disservices even for shorter and younger street trees. The results also demonstrate how differences in tree species influence the amount of ED, which are therefore unevenly distributed along city streets. For this reason, it is important to use appropriate species selection criteria in replanting trees or in new plantations, and use high quality materials to replace felled trees. Our results highlight that a better understanding of ED is still needed to establish an efficient green infrastructure, which can make urban environments more resistant and resilient.

CRedit authorship contribution statement

Emanuela Masini: Conceptualization, Data curation, Resources, Writing – original draft. **Antonio Tomao:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Supervision. **Piermaria Corona:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Lorenzo Fattorini:** Methodology, Formal analysis, Writing – review & editing. **Diego Giulirelli:** Conceptualization, Resources, Writing – review & editing. **Luigi Portoghesi:** Project administration, Conceptualization, Writing - review & editing. **Mariagrazia Agrimi:** Conceptualization, Funding acquisition, Project administration, Writing - review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.ufug.2023.128007](https://doi.org/10.1016/j.ufug.2023.128007).

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