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DATABASE

ATENA: dATabase of ornamEntal non-NAtive trees of seven Italian cities

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Abstract
Ornamental non-native trees play a key role in urban landscapes, enhancing the aesthetic appeal and providing many ecosystem services. This paper aims to present the database ATENA (dATabase of ornamEntal non-NAtive trees of seven Italian cities), which includes taxonomic information, ecological traits, and indicators of non-native ornamental trees of public spaces in seven representative Italian cities (Milan, Turin, Asti, Pavia, Rome, Campobasso and Palermo). The checklist includes a total of 317 plant taxa, with most originating from temperate Asia, North America, and tropical Asia. Zoochory is the primary mode of dispersal, followed by anemochory. When looking at the distribution of ornamental non-native trees across seven different cities, it is notable that the majority of these species are found in only one city. Furthermore, more than half of the species with unique occurrences are from Palermo. In the analysed Italian cities, we observed that the majority of the species used as ornamental trees are alien (54.8%), of which 8.2% are invasive taxa, while 45.2% are only cultivated. This raises concerns about the risks associated with planting non-native species that are invasive or potentially invasive, despite the well-documented negative impacts these species can have on native biodiversity. The ATENA database is a crucial resource for urban afforestation and the planning and design of green spaces, as it allows highlighting and avoiding species that are listed as invasive alien plant species. ATENA db is an open-access database designed for continuous updates, allowing for the inclusion of new traits and species from other Italian cities.

Keywords Alien plant taxa · Traits · Ecological indicators · Urban biodiversity · Public green space

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Introduction

Ornamental trees, often including non-native species, are widely planted in urban areas for their aesthetic and recreational value, as well as their ability to improve environmental conditions (Domina et al. 2020; Venturella et al. 2024). In particular, they can mitigate air pollution and temperature, thereby reducing the Urban Heat Island effect. Their use in parks, gardens, and lining streets provides aesthetic appeal and recreation areas and may become an integral part of the urban landscape (Domina et al. 2020; Schwaab et al. 2021; Ettinger et al. 2024).

Recent research emphasizes the predominance of exotic species (mostly Asian and American species) among ornamental trees along the streets of 15 Italian cities (Bartoli et al. 2022). These alien taxa introduced into urban green spaces often have more advantages than disadvantages compared to native species (de Carvalho et al. 2022). However, the increasing occurrence of non-native ornamental species that have escaped from cultivation and grow spontaneously in urban areas presents several environmental risks (Kowarik 2005). For instance, escaping alien species can act as propagule sources for secondary release and can have negative impact on adjacent natural habitats (Gaertner et al 2017; Parker et al. 2013), they are an emerging challenge for the conservation of heritage sites (Celesti-Grapow and Ricotta 2021) and can have negative impact on native plant biodiversity through changing biotic interactions (Čeplová et al. 2017).

To the best of our knowledge, at both European and Italian level, there are only few databases that focus on the diversity and distribution of non-native trees across cities (e.g. Sjöman et al. 2012; Schlaepfer et al. 2020; Bartoli et al. 2022), while only a few currently provide a range of information, including taxonomic features, ecological traits, or indicators, but they concern city-specific checklist of ornamental trees cultivated in urban public spaces (Venturella et al. 2024; Di Gristina et al. 2025; de Francesco et al. 2025; Musarella et al. 2024). To bridge this knowledge gap, we created a database that includes information on ornamental non-native trees in seven Italian cities, called ATENA (dATabase of ornamEntal non-NAtive trees of seven Italian cities).

The research was carried out within the framework of the National Biodiversity Future Center (NBFC), the first National Research and Innovation Center dedicated to biodiversity in Italy and funded by the Italian Ministry of University and Research (MUR) through European Union funds—NextGenerationEU. The NBFC is a national and international reference for generating knowledge and value from biodiversity and transferring them to the society and city administrations to implement ecosystem services, promote people's well-being, and generate social and environmental economic value (https://www.nbfc.it/en).

In this paper we provide an overview of the dataset of the relational database ATENA, focusing on taxonomic composition of non-native tree taxa in cities, their resident time and status, origin area and biome, generative diaspores, dispersal modes and leaf types.

ATENA database aims to offer a wide range of applications across multiple disciplinary domains, spanning from scientific research to urban and landscape planning. The available information can be used by different categories of stakeholders, including urban green space managers, ornamental plant suppliers, researchers, and technicians, to inform and improve ecological restoration initiatives. In addition, it supports the design and implementation of more sustainable urban greening strategies by promoting the careful selection of species and preventing the use of tree taxa that may threaten biodiversity, such as invasive alien ones.

Fig. 1 The seven Italian cities where non-native ornamental trees in urban public areas were recorded: Milan and Pavia (Lombardy), Turin and Asti (Piedmont), Rome (Lazio), Campobasso (Molise), and Palermo (Sicily)

Table 1 Cities included in the study along with their Ecoregional Province (Blasi et al. 2018), mean altitude (m a.s.l.), urban area (km^2) and number of inhabitants (ISTAT 2025)

City	Ecoregional Province (Blasi et al 2018)	Altitude (m a.s.l.) (ISTAT 2025)	Urban area (km^2) (ISTAT 2025)	Inhabitants (ISTAT 2025)
Milan	Po Plain	138	181.85	1,371,499
Turin	Po Plain	239	130.00	851,199
Asti	Po Plain	123	151.31	73,401
Pavia	Po Plain	77	62.21	71,297
Rome	Tyrrhenian	21	1,288.19	2,751,747
Campobasso	Apennine	701	56.11	47,418
Palermo	Tyrrhenian	14	160.67	630,427

Methods

Study area

The study area encompasses seven Italian cities distributed across a gradient of latitude and extent: Milan, Turin, Asti, Pavia, Rome, Campobasso and Palermo (Fig. 1 and Table 1).

Data collection

Data was collected from published (https://www.censimentodelverde.it/- updated to 2024; http://geoportale.comune.torino.it– updated to 2025; https://dati.comune.milano.it– updated to 2024) and unpublished green censuses carried out by municipalities; further data came from scientific publications (Celesti-Grapow and Ricotta 2021; Bartoli et al. 2022; Varricchione et al. 2024; Di Gristina et al. 2025).

Structure and content of the dataset

The ATENA database was created using the PostgreSQL data management system (PostgreSQL Global Development Group 2024).

We compiled a comprehensive database encompassing ecological information on recorded ornamental non-native trees across seven cities in Italy. For each taxon, we gathered information on 39 attributes (Supplementary Appendix 1). The ATENA database comprises four interconnected tables, each storing specific information on taxa and their ecological traits (Supplementary Appendix 2).

The 'TAXONOMY' table contains taxonomic data, including scientific names, nomenclature according to World Flora Online (WFO 2024) and Plants Of the World Online (POWO 2024) authorship information, the accepted name and families according to the Italian checklist of alien flora (Galasso et al. 2024) and subsequent updates as continuously integrated into the Portal of the Flora of Italy (2024), and whether the species are listed in the European, national, and regional regulations for non-native plants in Italy (Brundu et al. 2020).

The 'ECOLOGICAL_INDICATORS' table provides ecological indices for each taxon, including the European Indicator Value's for Europe 1.0 (EIVE) (Dengler et al. 2023), such as Moisture (EIVE-M), Nitrogen (EIVE-N), Reaction (EIVE-R), Light (EIVE-L) and Temperature (EIVE-T), as well as additional Ellenberg Indicator Values for the alien vascular flora of Italy (Domina et al. 2018), such as Light (L), Temperature (T), Continentality (K), Soil moisture (F), Soil Reaction (R) and Soil Nutrients (N) (Supplementary Appendix 2).

The 'TRAITS' table records functional and biological traits including: plant growth form, dispersal mode, generative diaspore type, plant height, leaf type, and leaf phenology (Table 2), leaf area, leaf nitrogen per mass (Nmass), leaf mass per area (LMA), diaspore mass, and stem specific density (SSD) (Díaz et al. 2022). These traits were selected because they are directly linked to the ability of species to establish and persist in stressful urban environments, while also providing insights into their potential invasiveness (Williams et al. 2015). For example, dispersal mode and diaspore type inform on the capacity of species to spread and colonize new areas (Wilson et al. 2009; Seebens 2019); plant height, leaf type, and phenology affect competitiveness and resource use strategies (Castro-Díez et al. 2003) and traits such as LMA, Nmass, and SSD are widely recognized indicators of ecological strategies, reflecting trade-offs between growth, survival, and stress tolerance (Poorter et al. 2009; Pavanetto et al. 2024). Including such information characterizes species biology and supports ecological and management questions. This includes identifying functional strategies that favor invasion and assessing traits associated with resilience to urban pressures.

The 'DISTRIBUTION' table records information on the occurrence and frequency of taxa across the seven Italian cities (Milan, Turin, Pavia, Asti, Rome, Campobasso and Palermo), with dedicated columns for each monitored city, and reports only presence/

Table 2 Description of each plant trait recorded in the table "TRAITS" of the ATENA database

PLANT TRAITS	Description
Plant growth form	Plant growth forms are non phylogenetic classifications of species that share similar trait combinations and represent key ecological strategies of plants in relation to their environment (Taylor et al. 2023). The growth form categories (Raunkiær 1934) occurring in ATENA dataset are scapose phanerophyte (P scap), caespitose phanerophytes (P caesp), and lianose phanerophytes (P lian)
Generative diaspore type	Generative diaspore refers to the dispersal units that are tied to sexual reproduction and are not vegetative in their nature, e.g., seeds, fruits, and include any appendages serving a role in dispersal (Van der Pijl 1982; Boedeltje et al. 2004; Sádlo et al. 2018). Our categories were developed considering form and dispersal capacity (and related dispersal vectors) and tailored to our species list. The seven generative diaspore categories adopted in the ATENA dataset are described in Supplementary Appendix 3
Dispersal mode	Dispersal mode refers to the transport of generative diaspores by different vectors such as wind, water, and animals (Thorsen et al. 2009; Pérez-Harguindeguy et al. 2013; Poschlod et al. 2013). The primary dispersal mode categories adopted in the ATENA dataset are described in Supplementary Appendix 4
Plant height	Plant height (m) is the maximum height reached by a typical mature individual of a species in a given habitat (Pérez-Harguindeguy et al. 2016). The plant height values adopted in the ATENA dataset are described in Supplementary Appendix 2
Leaf type	Leaf types in woody plants, which are often used for the physiognomic classification of forest and scrub vegetation, can be distinguished based on their morphology, anatomy, and lifespan. The ATENA dataset includes five leaf type categories retrieved by the FloraVeg.EU dataset (Chytrý et al. 2024): broad deciduous or semi-deciduous, sclerophyllous, needle-like, scale-like, and other. We introduced two leaf type categories that were not present in the FloraVeg.EU dataset: broad evergreen (including also laurophyllous) and palm-like. This addition helps better to classify all the leaf types occurring in the ATENA database (Supplementary Appendix 5)
Leaf phenology	The leaves of different woody plant species have distinct phenological patterns, and for Europe four categories are recognized (Chytrý et al. 2024): evergreen, winter deciduous, winter semi-deciduous, and drought semi-deciduous (Supplementary Appendix 5)
Leaf area	One-sided surface area of an individual lamina (unit: mm^2; in case of compound leaves the area of a leaflet lamina) (Díaz et al. 2022). The sources for leaf area values reported in ATENA are listed in Supplementary Appendix 2
N mass	Leaf nitrogen content per unit of lamina dry mass (leaf total N; unit: mg g^{-1}) (Díaz et al. 2022). The sources for N mass values reported in ATENA are listed in Supplementary Appendix 2
LMA	Leaf dry mass per unit of lamina surface area (unit: g m^{-2}) (Díaz et al. 2022). The sources for LMA values reported in ATENA are listed in Supplementary Appendix 2
Diaspore mass	Dry mass of an individual seed or spore plus any additional structures that assist dispersal and do not easily detach (unit: mg) (Díaz et al. 2022). The sources for diaspore mass values reported in ATENA are listed in Supplementary Appendix 2

Table 2 (continued)

PLANT TRAITS	Description
SSD – Stem Specific Density	Stem specific density (SSD) (unit: mg mm^{-3}) is the stem dry mass per unit of stem fresh volume (Díaz et al. 2022). The sources for SSD values reported in ATENA are listed in Supplementary Appendix 2

absence rather than quantitative data. It also includes data on the status of the species as archaeophytes or neophytes in Italy (according to Celesti-Grapow et al. 2009; Galasso et al. 2024), as well as their origin area and origin biome (POWO 2024; WFO 2024).

Data analysis

In order to provide a comprehensive description of the ATENA database, we first calculated the percentage of taxa in each family in order to give an overview of the representativeness of each taxonomic family in the analysed Italian cities. Families represented by less than 3% of the total taxa were grouped into the "Others" category.

We then determined the percentage distribution of taxa based on their growth form and plant height, categorizing the species in megaphanerophytes (> 30 m tall), mesophanerophytes (with plant height ranging from 8 to 30 m) and microphanerophytes (with plant height between 2 and 8 m) (Niklas 2008).

Subsequently, we calculated the proportions of each non-native species based on the status of alien species in Italy (Galasso et al. 2024; Portal to the Flora of Italy 2024). Species not recorded as spontaneous in Italy (according to Galasso et al. 2024) were classified as 'only cultivated'. In addition, we analysed the relative percentage of each geographic and biome origin class.

Regarding the biome of origin, the categories "seasonal dry tropical" and "wet tropical" were grouped within the "tropical" biome, as they are its subcategories. Moreover, we characterized the species list by analysing the ratios of generative diaspore, dispersal mode and leaf type.

In the dispersal mode chart, we calculated the proportion of the four highest-rank categories: anemochory, autochory, hydrochory, and zoochory. Subsequently, within the zoochory category we calculated the proportion of subcategories: dyszoochory, endo-ornithochory, endozoochory, and myrmecochory.

Finally, we calculated the frequency distribution of each plant taxon across the seven Italian cities included in the database.

All analyses were conducted using R Statistical Software (v4.4.2. R Core Team 2024), with plots generated using the "ggplot2" package (Wickham 2016).

Results

The checklist encompasses a total of 317 plant taxa, belonging to 72 families. The most represented families are Rosaceae (10%), followed by Fabaceae (8%), Pinaceae (7%) and Arecaceae (7%) (Fig. 2A).

The majority of taxa are scapose phanerophytes (P scap, 74.4%), followed by cespitose phanerophytes (P caesp, 25.6%). Within these, half of the species (50%) are classified as mesophanerophytes, 32.7% are microphanerophytes, and 17.3% are megaphanerophytes.

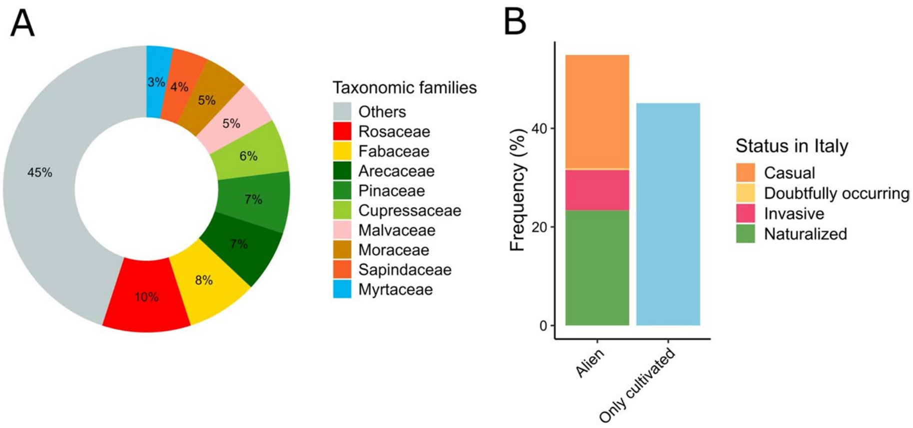

Fig. 2 (**A**) Representativeness of taxonomic families in ATENA Database; families representing less than 3% of the total are grouped under 'Others'. (**B**) Frequency of alien and only cultivated taxa in ATENA database for their status in Italy, according to (Galasso et al. 2024)

More than half of taxa consist of alien trees escaped from cultivation in Italy (54.8%), while the remaining part is characterized by plant taxa not reported in Galasso et al. (2024) and classified as only cultivated (45.2%) (Fig. 2B).

Notably, only 23.0% of alien taxa are reported as casual in Italy, with similar proportions classified as naturalized (23.3%) and a smaller share as invasive (8.2%). One taxon is recorded as a doubtful occurrence for Italy (Fig. 2B).

The rate of invasive alien used for ornamental purposes in the studied cities, like *Acacia saligna* (Labill.) H.L.Wendl. or *Ailanthus altissima* (Mill.) Swingle, which are also reported as invasive alien species of Union concern (Regulation EU n. 1143/2014), is non-negligible.

These species cause negative impacts on biodiversity and human activities and may establish in natural environments, determining important ecosystem modifications (Celesti-Grapow and Ricotta 2021; Campagnaro et al. 2022). Although not all introduced plants become invasive, the ability to become invasive should not be underestimated, both for casual and naturalized alien taxa (Musarella et al. 2024).

Considering the geographic origin area, the majority of the taxa come from temperate Asia (32.7%), followed by Northern America (20.6%), tropical Asia (13.3%) and Australasia (10.7%) (Fig. 3A). However, in terms of biomes of origin, most of the taxa come from temperate biomes (53.5%), followed by tropical (24.8%) and subtropical (18.6%) ones (Fig. 3B).

Concerning the proportion of generative diaspore types, the most common (42.8%) are the fleshy generative diaspores, which are generally attractive to animal dispersers and often offer some nutriment (Fig. 4A). The winged category was the second largest (28.2%) and not only includes the species with obvious samaras but also species with associated appendages serving the same purpose. Unspecialized diaspores (19.5%) have no obvious adaptations for dispersal that rely on other entities but rather are dispersed primarily by gravity or ballistically. The non-fleshy indehiscent category includes heavy, nutritious diaspores that tend to be eaten (and dropped en route) or cached (and forgotten), and comprise 6% of the species. Species in the pappose category (1.9%) produce diaspores with tuft(s) of hairs that increase wind resistance and extend dispersal distance by slowing diaspore descent. Finally, only acacias belong to the elaiosomate category (1.6%); ant-mediated dispersal may vary from other zoochorous

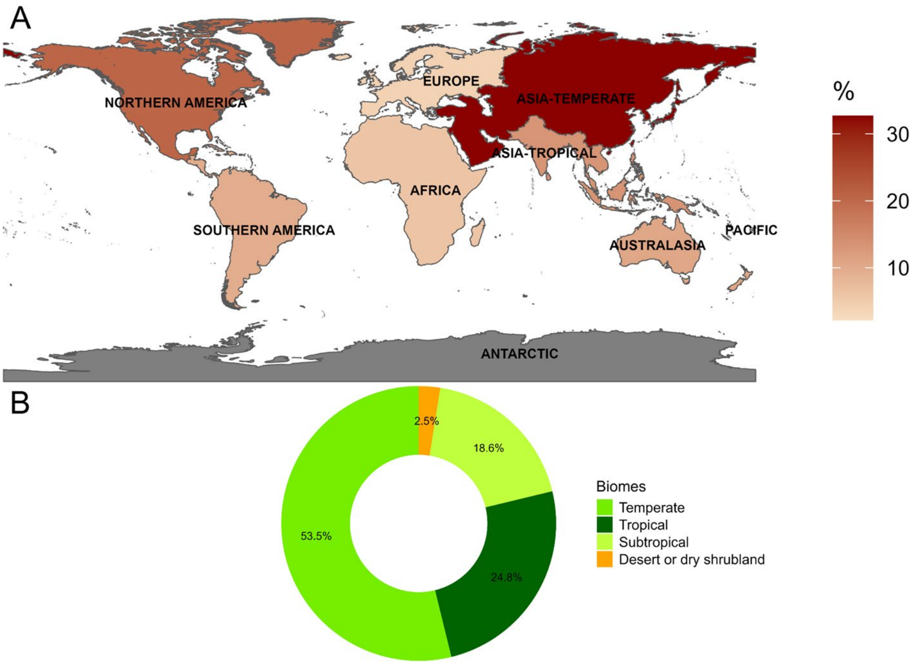

Fig. 3 Origin area and native biome of taxa included in ATENA Database. (**A**) Sub-continent of origin according to World Flora Online (WFO 2024); (**B**) Biome of origin according to Plants of the World Online (POWO 2024)

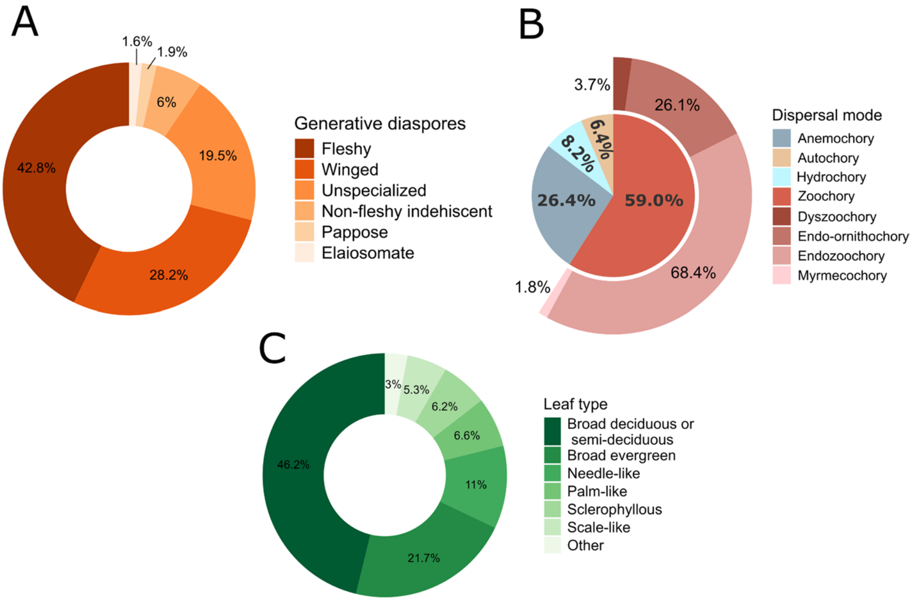

Fig. 4 Proportions of different generative diaspore types (**A**), dispersal mode categories (**B**) and leaf types (**C**) of the ATENA Database taxa

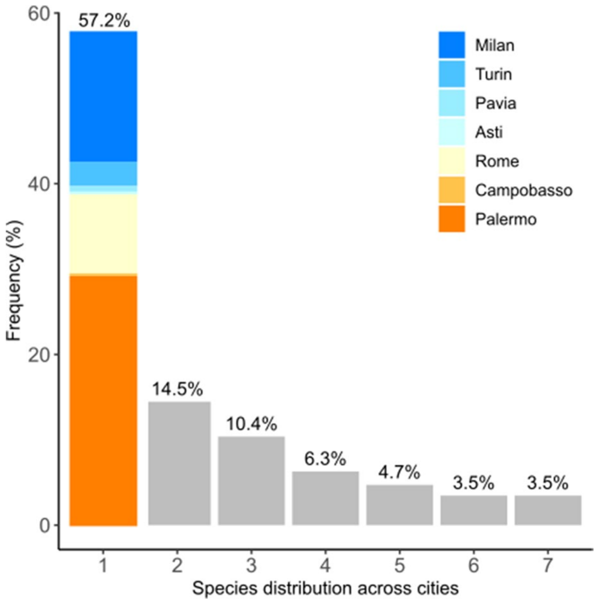

Fig. 5 Bar chart illustrating the percentage (%) of taxa in the ATENA database classified by their occurrence across the seven Italian cities. The first bar represents the number of taxa found in only one city, with a stacked colour representation indicating the contribution of each city; bars 2–7 show the percentage of taxa occurring in only 2, or more (7) cities

dispersal patterns in unexpected ways (Richardson and Kluge 2008) and may be additionally informative within the urban context.

Half of the taxa have a single mode of dispersal. The other half were associated with two, three, or four modes of dispersal, in varying combinations. Only three species in our list were reported to exhibit four modes of dispersal: *Acer negundo* L., *Albizia julibrissin* Durazz. and *Carya ovata* (Mill.) K.Koch.

Overall, the most widespread dispersal mode across the ATENA plant taxa is zoochory (59.0%), followed by anemochory (26.4%), hydrochory (8.2%) and autochory (6.4%) (Fig. 4B). Within the zoochory dispersal mode, 68.4% are classified as endozoochory, followed by endo-ornithochory (26.1%), dyszoochory (3.7%) and myrmecochory (1.8%). Moreover, regarding the leaf type, broad deciduous or semi-deciduous are prevalent (46.2%), followed by broad evergreen species (21.7%) and needle-like (11.0%) (Fig. 4C). The other leaf type categories are less represented, each comprising less than 10% of the taxa.

Regarding the distribution of ornamental species in the ATENA database across the seven different cities, only 3.5% are present in all cities, while 57.2% are found in only one of the seven cities. Specifically, more than 50% of the species with a unique occurrence are from Palermo, followed by 26% from Milan and 16% from Rome (Fig. 5).

Conclusions and future perspectives

ATENA, developed by a national team of researchers from the National Biodiversity Future Center, is the first database with multivalued attributes referring to the non-native ornamental trees of public areas in Italian cities.

It includes taxonomic, chorological, ecological, and functional traits data. This digital and accessible archive is designed to be continuously updated, with new data collected from other cities across Italy, as well as additional traits, such as reproductive strategy, shade tolerance, sun exposure, and data on disservices, such as allergenicity.

The database offers valuable data for urban afforestation and green space design, focusing on the ecological and functional traits, as well as the invasiveness of non-native ornamental trees in seven Italian cities. Because it also reports invasive alien taxa, it can be used to stress to local administrators the importance of avoiding the use of these invasive tree species in future urban greening projects. These species can not only have negative impacts within urban areas but may also spread to surrounding regions, as cities often act as centres for the introduction and spread of invasive species into nearby anthropogenic and natural areas.

Future research aims to classify non-native ornamental taxa into groups based on their suitability and adaptability to current and future forecasted scenarios of urban climate. This facilitates the identification of alien tree species that could become potentially invasive due to their ecological characteristics and dispersal potential.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s44473-025-00039-8.

Authors' contributions CM, SC, EB, FL and LC conceived the research network idea. AS, MV, NS, GD and LAS conceptualised the study, and wrote the first draft of the manuscript with substantial inputs from LC, CM, EB, GV, MLC and SC, MV, NS, GB, GD, LM, LAS, EDG and EV organised, managed and analysed the data. All the authors provided the data and contributed to the critical revision of the manuscript to produce the final version.

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Data availability The database is stored in Zenodo repository at the following link: https://doi.org/10.5281/zenodo.15861218.

Declarations

Conflict of interest The authors declare that they have no conflict of interest in the publication.

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