



An interdisciplinary approach integrating dendrochronology, botanical data, and archival sources to reconstruct the historical evolution of a garden: the case of Villa De Capoa, an urban garden in the Mediterranean basin

Vittorio Garfi^{1,3} · Roberto Parisi² · Piera Di Marzio^{1,3} · Eduardo Antenucci¹ · Soraya Versace¹ · Luca Quaranta¹ · Felisia Miele² · Paola Fortini^{1,3}

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Abstract

Historic gardens constitute a significant dimension of Italy's cultural heritage, reflecting the connection between vegetation and architectural elements. This study focuses on Villa De Capoa, a historic public garden in Campobasso municipality where 350 trees were surveyed, comprising 181 angiosperms and 169 gymnosperms. Since documentation on the garden's origins and changes is limited, an interdisciplinary method combining archival research, botanical surveys, and dendrochronology was used to reconstruct its development. Dendrochronological analysis identified three main phases of intervention, confirming the historical hypothesis: the initial neoclassical design (1830s–1850s), represented by oldest trees of *Cupressus sempervirens*; after modifications subsequent its donation to the Campobasso Girls' Orphanage (1870s–1880s), marked by *Aesculus hippocastanum* plantings; and the 1930s redesign reflecting fascist-era rationalist aesthetics, with *Sequoia sempervirens* and *Cedrus deodara*. Age structure analysis also identified three areas: Area 1 shows the widest age variability among its trees (52–182 years), the outcome of a series of successive and overlapping interventions. Area 2 features a coherent group (140–187 years), indicating a relatively unified planting activity. Area 3 uniform 1930s plantings. This interdisciplinary approach helps clarify planting sequences, verify historical interpretations, and supports conservation planning for gardens both as cultural and ecological heritage sites.

Keywords Historic gardens · Dendrochronology · Botanical heritage · Archival sources · Urban environments

✉ Eduardo Antenucci
e.antenucci2@studenti.unimol.it

¹ Department of Bioscience and Territory, University of Molise, Contrada Fonte Lappone, 86090 Pesche, Italy

² Department of Human and Social Sciences and of Education, University of Molise, Via De Sanctis Snc, 86100 Campobasso, Italy

³ National Biodiversity Future Center (NBFC), 90133 Palermo, Italy

Introduction

The Italian landscape is enriched by historic gardens that are a vital part of the country's cultural heritage. According to the International Council on Monuments and Sites – International Federation of Landscape Architects (ICOMOS-IFLA 1981, 2017), a historic garden is defined as an architectural and horticultural composition that holds public interest due to its historical or artistic significance. For this powerful combination, a historic garden can be defined as a dynamic living system lasting over time. This concept is remarkable in the Operation Guidelines for the Implementations of the World Heritage Convention (UNESCO 1992), where it is underlined that it is also a particular type of cultural landscape (item 1): an example of human intentional creation and design of nature. From this perspective, historic gardens' values lie precisely in their diverse heritage attributes, which show transformation of a special natural environment conducted by human culture and address different scales of time and space (Connell 2005; Gothein 2014).

In Italy, the most significant historic gardens are often referred to as "*Giardino all'Italiana*" (GI), also known as the "formal garden". This type of garden, which originated in Italy during the late Renaissance, around the mid-sixteenth century, in the castles and villas of the upper bourgeoisie, holds a rich historical significance. It represents an evolution of the *hortus conclusus* (garden enclosed by high walls), the typical medieval garden primarily associated with monasteries and convents. The GI is characterized by a profound geometric division of spaces, tree-lined avenues and/or hedges, plant sculptures of various shapes obtained through the pruning of evergreen shrubs (topiary) such as *Buxus sempervirens* L., and geometric water features, often accompanied by architectural elements such as fountains and statues.

The green component of the GI was organized as a "Collection of Plants", with a special emphasis on the inclusion of exotic species from all continents, a feature that was highly valued. Today, the original green component comprises trees that are several decades old, with some reaching 200–300 years. As a result, these trees have grown to considerable heights, with significantly increased trunk diameters based on planting data. From this perspective, historic gardens play a crucial and irreplaceable role in biodiversity conservation strategies, particularly in enhancing the green component. Over the past decade, vegetation has been increasingly challenged by climate change, especially in the Mediterranean region (Carrari et al. 2022). Alongside the rapid shifts in climatic variables, there has been a marked rise in phytosanitary issues and biological invasions (Paap et al. 2017), contributing to the deterioration of garden conservation (Carrari et al. 2022). This decline in plant species richness can cascade through other trophic levels, ultimately compromising the functionality of ecosystem services vital to human well-being (Mace et al. 2012). The preservation, maintenance, and restoration of historic green gardens have garnered increasing attention, driven not only by the accelerating impacts of climate change (Martin 2015) but also by the ongoing expansion of urbanization (Rostami et al. 2015; Fineschi and Loreto 2020). Modern cities face growing challenges in developing resilience and sustainability to counter urban sprawl (Giddens 1996; Ozdemir 2007) and improve urban quality of life (Alberti and Marzluff 2004; Rostami et al. 2015; Antenucci et al. 2025). Environmental changes pose significant risks to citizens' health and well-being, making the ecosystem services provided by green spaces, such as historic gardens, essential allies in mitigating and adapting to climate change (Matteini 2021).

Proper management of green spaces, including the preservation and upkeep of parks and historic gardens, ensures better access to natural resources, enhances social

interactions, and promotes well-being (Giles-Corti et al. 2016; Olivadese and Dindo 2022). Additionally, these gardens serve as cultural landmarks, fostering identity, memory, and a sense of belonging, while offering substantial social and psychological benefits (Rostami et al. 2015).

The restoration of historic gardens relies on comprehensive studies that combine botanical investigations, such as identifying species and assessing their condition using forestry measures (Avdić et al. 2013), with historical and archival research to understand their design and compositional features (Nestor and Mann 1998; Gullino et al. 2020). However, many historic gardens suffer from incomplete documentation regarding their origins, initial designs, chronological development, and subsequent modifications, often leaving gaps in their historical records.

In this framework, “Villa De Capoa” garden located in Campobasso municipality (Southern Italy, Mediterranean area) is included in this category. This historic urban public garden lies within the perimeter of the historical centre, as defined by the Campobasso Municipal Urban Plan, and is subject to landscape preservation regulations as established by the legislative references to the local heritage authority (Ministero della Cultura 2023). Although some archived documents provide insights into the garden’s layout and history, they are fragmented and lack critical information. For instance, the exact date of the villa’s foundation remains unknown, and the hypothesis of its 18th-century origins has not been proved by documentary evidence (Parisi and Miele 2023). The current research proposes a method to reconstruct the origin and historical transformations of “Villa De Capoa” garden by analysing the ages of the trees planted within it and comparing the results with the limited surviving historical documents. The study has the potential to significantly enhance our understanding of historical landscapes. To determine the age of the trees, we employed dendrochronology, a scientific technique that uses tree rings to date past events and reconstruct historical environmental conditions (Dean 1997). Dendrochronology has been widely applied in studies examining tree growth responses to climate change (e.g., Carrer and Urbinati 2004; Battipaglia et al. 2009; Schuster and Oberhuber 2013; Merlin et al. 2015; del Río et al. 2021; Gauli et al. 2022), in reconstructing past climates (e.g., Martinelli 2004; Campelo et al. 2009; Schofield et al. 2016) and in past management (e.g., Motta and Lingua 2005; Haneca et al. 2005; Muigg et al. 2020; Garfi and Garfi 2024). Additionally, dendrochronological techniques are extensively used in archaeology, art history, and architectural history—fields concerned with cultural heritage—to determine the age and provenance of wood used in historical and prehistoric artefacts and structures (e.g., Čufar 2007; Martinelli et al. 2014; Domínguez-Delmás et al. 2015; Dinca et al. 2025; Martinelli 2025). In this context, the aims of this paper are to:

- (1) Determine the age of the old trees (e.g., those with the largest trunk) through dendrochronological analysis,
- (2) Investigate the landscape transformations of the historic garden by comparing dendrochronological data With historical and cartographic documentation,
- (3) propose a methodological approach for studying the origins and transformations of historic gardens.

The insights gained from this case study could provide a valuable framework for understanding the historical development of other gardens and for guiding the sustainable management of their trees. Tracking the evolution from the past to the present is

essential for grasping the natural, historical and philosophical aspects of these spaces and for ensuring their long-term preservation.

Material and methods

Study area

We conducted the study in the Villa De Capoa Garden, located in Campobasso municipality at an altitude of 700 m a.s.l., approximately 70 km from the Adriatic Sea (Fig. 1). The garden covers an area of 1.6 ha and has a current layout resembling an inverted “L”. It is situated south-west of the medieval core of Campobasso’s old city, adjacent to Piazza Falcone e Borsellino, and extends toward the late 20th-century expansion area near Via Duca d’Aosta. The site is bordered on the north-east by residential buildings and on the south-east by sports facilities.

Historical background

We divided the historical research on the Villa De Capoa into three operational phases. The first phase involved direct investigation of the study area and a photographic survey of the same area.

The second phase of the project entailed the identification, collection, and digital acquisition of bibliographic and historical-documentary material from public and private libraries and archives.

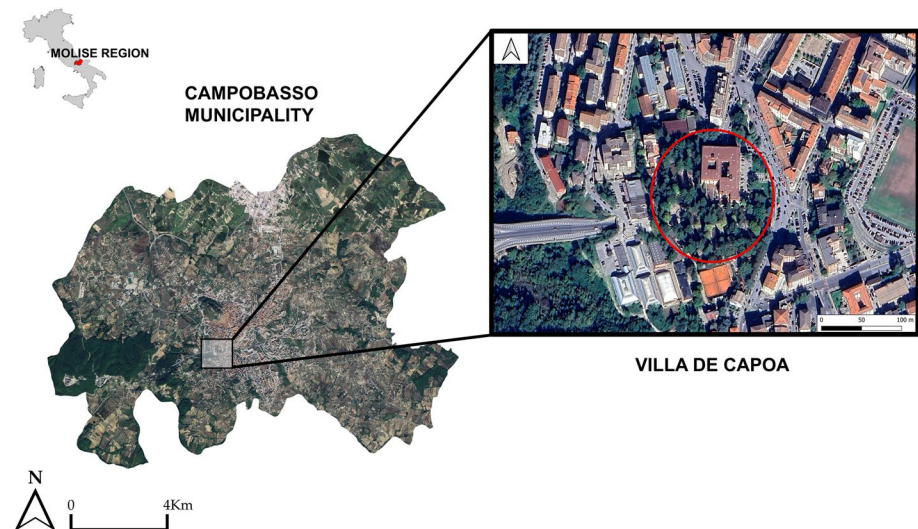


Fig. 1 Location of Molise region in Italy (red color), and the location of Villa De Capoa in the Campobasso municipality (red circle)

We conducted the third operational phase through the investigation of the archived material surveyed and the historical–critical analysis of the sources. This analysis was useful in the reconstruction of all the evolutionary phases of the Villa.

We carried out the documentary investigation at the National Archives, in particular, and the Municipal Historical Archives of Campobasso. The research process involved the consultation of over 20 archival collections, resulting in the digitisation of approximately 8,000 loose sheets.

The green component

As part of the project “*The Historic Garden of Villa De Capoa: Between Biodiversity and Sociality*” (PNRR Call, Mission 1, Measure 2, Investment 2.3), we conducted a botanical survey of trees and shrubs, providing an updated census of the plant species present in Villa De Capoa as of June 2023 (Fortini et al. 2023). The updated work involved systematic data collection, the identification and census of the individuals for each flower bed and intermediate areas (from Area 1 to Area 3 and all the sectors: B, C, D, E, F) (Fig. 2). In addition, for each tree, we measured the trunk diameter at breast height (DBH—two measurements with a traditional dendrometric caliper, then averaged), and for each tree or shrub, the height was measured using a TRUPULSE 360 (Laser Technology Inc., USA), a laser rangefinder with an integrated clinometer and compass (azimuth) function. Species identification follows Pignatti et al. (2017) and the nomenclature follows the most up-to-date Portal to the Flora of Italy v.2024.3 (2024). For each species, we integrated information relating to biological forms and chorotypes Pignatti et al. (2017), POWO (2025),

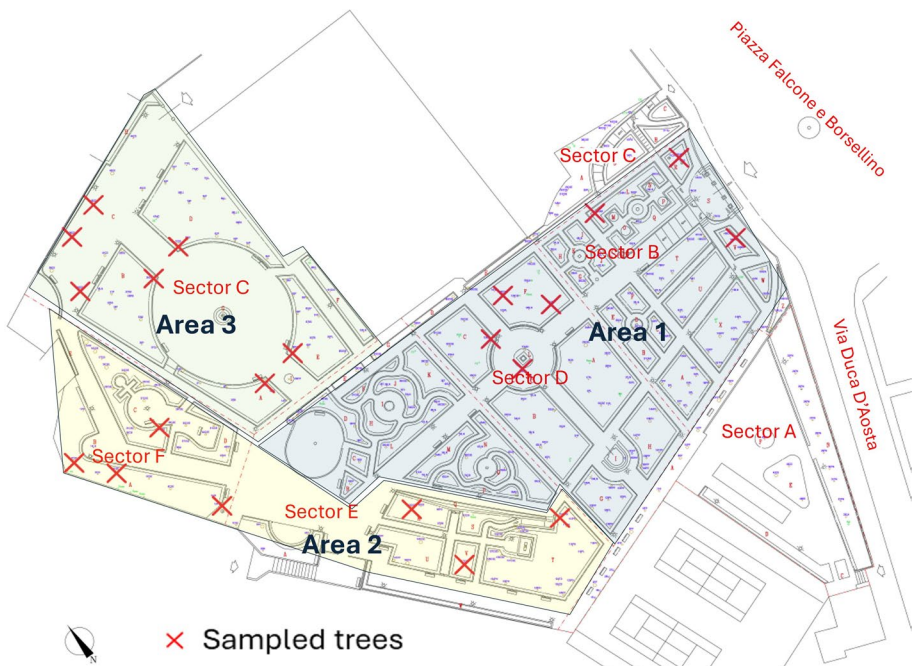


Fig. 2 Garden map with different areas and locations

exoticity/indigenoussness (Portal to the Flora of Italy 2024), status according to the international red list (Goodsell et al. 2025), status according to the Italian red list (Rossi et al. 2020), allergenicity (Frenguelli and Passaleva 2003; Cariñanos and Marinangeli 2021) and use/toxicity (Acta Plantarum 2025).

Tree sampling and ring width chronologies

Based on the historical analysis of the garden, we selected three areas of research (followed called as “Area” or “Areas”) (Fig. 2). These areas are presumed to differ in the years of tree planting and were identified using municipal cartography to cover the entire garden’s extent as follows:

- Area 1, presumed to be the oldest in terms of planting activity, includes:
 - Sector B (likely dating back to the end of eighteenth century and the 1920s–1930s),
 - Sector D (probably dating back to the nineteenth century),
 - The upper part of Sector E (likely dating back to the nineteenth and twentieth centuries).
- Area 2 includes:
 - Sector F (likely dating back to the nineteenth century),
 - The lower part of Sector E.
- Area 3 includes:
 - Sector G (dating back to 1929–1933).

We excluded Sectors A and C from the study as they have recently undergone redevelopment, including the construction of a children’s playground and a walkway.

The sampling was conducted in December 2023. Where possible, we selected two dominant taxa from each Area. This selection was based on dendrometric parameters, particularly tree diameter, under the assumption that larger-diameter trees are more likely to be older. The three trees with the largest diameters were identified for each taxon, except for the single *Pinus pinea* L. specimen. Additionally, we selected trees of other species with the largest diameters at each Area for subsequent core sampling. We collected core bores from 7 trees per Areas (in total, 21 trees). The dendrochronological sampling involved collecting woody samples (cores) using a Pressler increment borer. For each selected tree, two cores were taken at breast height (1.3 m above the ground) at 90° apart from each other (Motta 1996) (one North and the other East), and one was taken 30 cm above the ground on the North side. While, samples taken at a height of less than 50 cm have certain limits due to the irregularity of growth around the circumference in the lower part of the trunk, but on the other hand, they also provide more reliable data on age (Schweingruber 1996).

The extracted cores were processed following standard dendrochronological procedures (Schweingruber 1988). They were glued onto grooved wooden supports and then air-dried. Finally, they were sanded using progressively finer grades of sandpaper (from 80 to 400) to make the annual rings easier to read. The ring width series was measured with an accuracy of 0.01 mm using LINTAB measuring equipment paired with a Leica MS5 stereomicroscope. The TSAP™ software package (Rinn 2003) was used for analysis. The individual tree-ring width series were visually cross-dated for each species using TSAP™. Only those cores that cross-dated successfully, showing a significant *Gleichläufigkeit* (GLK; $P \leq 0.05$),

which quantifies the year-to-year agreement in ring-width fluctuations between two curves (Baillie and Pilcher 1973), were retained for further analysis. Subsequently, the accuracy and internal consistency of the resulting chronologies were assessed using the COFECHA software (Holmes 1983).

We used the individual chronologies to build up the age structure. Usually, the failure to intercept the pith for many cores and the unknown number of years required for plants of different ages to reach the sampling height (1.30 m) can lead to biases in terms of accuracy. The first limitation was mitigated to some extent by estimating the number of rings missing from the pith using the pith locator method (Applequist 1958) through the CooRecorder (version 9.8.4) software. Therefore, the cores were scanned at 600 dpi and uploaded to CooRecorder software in order to obtain the number of missing rings. Subsequently, to estimate the trees' actual age, the number of years needed to reach a coring height of 1.30 m was estimated. These were obtained from the difference between the number of rings of the chronology, taken at 30 cm and that of the chronology taken at the core sampling height at 1.30 m for the same tree. Finally, we determined the age structure of the stands in the three Areas by grouping the plants into 10-year age classes (Motta and Lingua 2005).

Results

Historical background

The precise origins of Villa De Capoa in Campobasso remain uncertain due to the absence of firm documentary evidence. A tax document dating back to 1688 provides evidence of the existence of a "large garden" in the same location as the Villa, which was owned by the Monastery of S. Maria delle Grazie, founded in 1510 (Ziccardi 1841).

The monastery was suppressed in 1809 and subsequently converted into an orphanage in 1810. In a topographical map from 1812 attached to an agronomic survey, its "large garden" is depicted as the primary component of a publicly owned tract of land dedicated exclusively to arable farming. Conversely, the documentary source in which the "Villa del Conte de Capua" is mentioned and depicted for the first time dates back to the years 1859–1861. The topographic map of the city of Campobasso under consideration was delineated by Antonio Pace in 1859 and printed by Pasquale Albino in 1861 (Parisi 2006). The map delineates the historic garden as a rectangular layout, characterized by three longitudinal pedestrian paths (one central and two peripheral), a central rotunda, and a series of transverse paths. Some of these elements remain partially preserved to this day. The longer side extended parallel to the southern façade of the former Monastery of *Santa Maria delle Grazie*, while one of the shorter sides corresponded to the present entrance to the park, facing Falcone and Borsellino Square.

Therefore, the foundation date of this initial garden layout can be traced to a chronological arc between 1812 and 1861. Its geometric design, with a clear neoclassical matrix, can be dated to approximately the first half of the nineteenth century, and the commission is likely to be attributed to the husband and wife Carlo De Capoa and Raffaella Salottolo.

Another document of relevance for understanding the origins of the historic garden and its subsequent transformations during the nineteenth century is the secret will of Marianna De Capoa, daughter of Count Carlo. The will was initially drafted in 1875 and later revised in 1876 by Marianna's mother, Raffaella Salottolo (Salottolo 1877). These two sources

indicate that the Villa De Capoa was donated in 1875 to the Campobasso Girls' Orphanage, founded by Marianna, and that between 1875 and 1876 the villa's casino underwent some extension work.

The shape and texture of the historic garden after these interventions can be inferred from the topographical map attached to Camillo Rosalba's "*Progetto di un Piano Regolatore per la città di Campobasso*" (1880)- Draft master plan for the city of Campobasso. The garden's layout, as delineated in this scheme, exhibits a clear division into two distinct sections. The first portion of the garden retains the geometric layout previously documented in the 1859–1861 map, exhibiting minor variations in the dimensions of the central rotunda and the design of the flowerbeds. In contrast, the subsequent portion, situated behind the former Monastery of *S. Maria delle Grazie*, exhibits a "picturesque" layout characteristic of landscape gardens, featuring irregularly shaped flowerbeds and winding paths. Moreover, within the confines of the Villa, two structures have since disappeared. These structures may potentially correspond to the farmhouse and the janitor's house, as referenced in an inventory of the orphanage's assets dating back to 1899.

The extant configuration of the Villa, however, is the result of a design drawn up in the early 1930s by Campobasso's chief engineer, Michele Jannucci. In fact, between 1930 and 1933, the municipality procured Villa De Capoa for its transformation into the "Villa Comunale del Littorio". During this period, several renovations were undertaken, including the consolidation of the boundary wall, structural changes that involved the creation of new spaces (the rectangular Belvedere, the oval Piazzale, the large elliptical square, and a Liberty kiosk), and the installation of the lighting system.

Finally, from 1977 to 2002, Villa De Capoa underwent further significant transformations, both infrastructural (expansion of the Villa, restoration projects subdividing the area into sectors, construction of a new kiosk, renovation of the premises behind the fountain-basin, etc.) and landscape-related (Cialdea 1997).

The green component

The field survey yielded a detailed census of the woody flora in Villa De Capoa, enabling quantitative analysis of taxonomic composition, structural attributes, and species abundances. We recorded a total of 350 individual plants in the garden (Table S1), comprising 181 angiosperms (belonging to 27 genera, 31 species, and one variety) and 169 gymnosperms (distributed across 13 species in nine genera). The families with the highest number of individuals were Pinaceae (three genera, four species), followed by Cupressaceae (four genera, four species), Lauraceae (*Laurus nobilis* L.), Rosaceae (five genera, seven species), and Fabaceae (four genera, four species) (Fig. 3).

More than a quarter of the native species present (Table 1) belong to the Mediterranean chorotypes (27.9%), followed by European taxa (18.6%); among individuals belonging to non-native species, most are from Asia (30.2%), followed by North America (14%) and, in rare cases, Africa.

The measurements of heights and diameters taken on all individuals of tree and shrub species in the garden show that the largest diameters were recorded for a *Sequoia sempervirens* (D.Don) Endl. tree (150 cm) followed by an individual of *Cupressus sempervirens* L. (107 cm), while the tallest trees were two *Cupressus sempervirens* individuals, reaching respectively 35.9 m and 35.3 m (Table S1). The sequoias are located in sector G (Area 3), the largest cypress is located in sector E (Area 1), and the tallest cypress trees in sector F (Area 2).

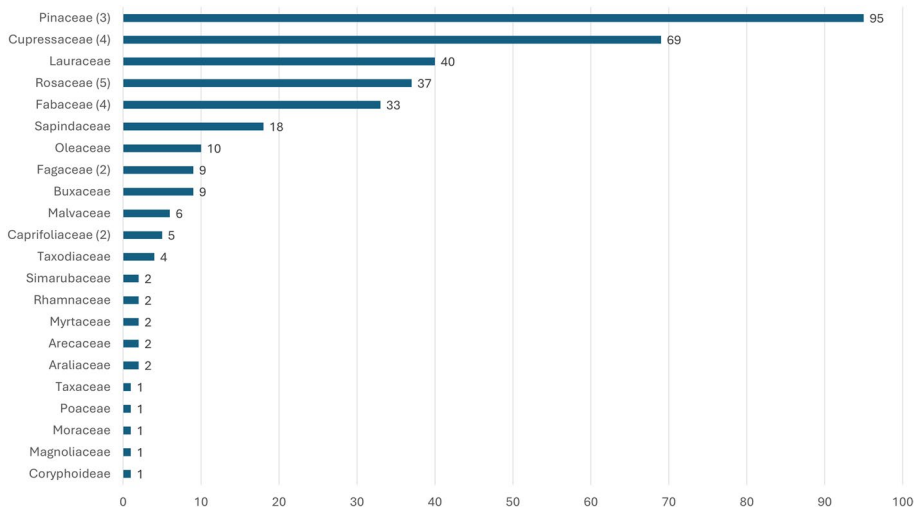


Fig. 3 Number of plant individuals per family. In brackets: the number of genera per family if > 1

The garden's structural conditions present several ecological and management challenges. Many tree canopies are densely crowded, leading to instability, reduced growth, resource competition, and extensive shaded areas. Numerous individuals show evidence of trunks cut at ground level, with vigorous basal sprouting; this is especially notable in *Cercis siliquastrum* L., *Laurus nobilis*, and *Ligustrum lucidum* W.T.Aiton. In contrast, species such as *Quercus ilex* L. and appear to regenerate spontaneously from seed.

From a conservation perspective, 38 taxa recorded in Villa De Capoa are included in the IUCN Red List of Threatened Species (Goodsell et al. 2025). Noteworthy among the gymnosperms are *Chamaecyparis lawsoniana* (Murray) Parl. and *Platycladus orientalis* (L.) Franco (= *Thuja orientalis* L.), both classified as Near Threatened (NT), and *Cedrus atlantica* (Endl.) Manetti ex Carrière and *Sequoia sempervirens*, both listed as Endangered (EN) with globally decreasing population trends. Among angiosperms, *Aesculus hippocastanum* L. is categorized as Vulnerable (VU), also with a declining global population. Also of interest is the occurrence of *Chamaerops humilis* L., an NT species included in the Italian Red List (Rossi et al. 2020).

Regarding alien taxa in Italy, five archaeophytes (all naturalized) and 18 neophytes were recorded. Among the latter, three are casual, ten naturalized, and five invasive: *Ailanthus altissima* (Mill.) Swingle, *Ligustrum lucidum*, *Prunus laurocerasus* L., *Robinia pseudoacacia* L., and *Trachycarpus fortunei* (Hook.) H.Wendl. Of these, only *Ailanthus* and *Robinia* genera are currently considered invasive in Molise region.

With respect to allergenic potential and following the classification by Cariñanos and Marinangeli (2021), 19 species fall into the low-risk category, 11 into moderate-risk cat., three into high-risk cat., and five into very high-risk cat. Additional references to Frenguelli and Passaleva (2003) identify four further species as low- or no-risk: one shrub (*Buxus sempervirens*), one climber (*Hedera helix* L.), and two trees (*Quercus pubescens* Willd. and *Sequoia sempervirens*). Finally, ethnobotanical analysis revealed the presence of one edible species, 15 edible/officinal species, ten officinal species, and nine officinal/toxic species (Table S1).

Table 1 Chorotype distribution of the species recorded, grouped into seven mains categories (in bold). Within each category, species were further assigned to regional sub-chorotypes (e.g. China, E-Asian, W-Asian—Pontic) following Pignatti et al. (2017) and POWO (2025) for the taxa not reported in Pignatti

<i>Chorotype</i>	<i>N. of species</i>	<i>%</i>
African	1	2.3
Asian	13	30.2
China	2	
China, Korea, Japan	1	
E-Asian	5	
SE-China	1	
S-Asian	1	
SW-Asian	1	
W-Asian (S-Pontic)	1	
W-Asian-Pontic	1	
Endemic illyric-E-alpine	1	2.3
European	8	18.6
Balkans	1	
C-European	1	
European Caucasian	1	
European-Subpontic	1	
Eurosiberian	1	
Orof. Eurasian	1	
S-European	1	
S-European-W-Asian (Pontic)	1	
Mediterranean	12	27.9
E-Mediterranean (Euri-)	1	
Eurimediterranean	2	
Mediterranean-mountainous	1	
N-Eurimediterranean	1	
Stenomediterranean	6	
W-Stenomediterranean	1	
N-American	6	14.0
Submediterranean/Subatlantic	2	4.7
Total	43	100%

Structural and dendrochronological analysis

We sampled a total of 21 trees (Table 2 and Fig. 4), and 62 increment cores were extracted in total. 42 at breast height (1.3 m) and 20 at 30 cm above ground level. Eleven cores were excluded from the dendrochronological analysis due to unsuccessful cross-dating, and two trees (4 CSE and 34 CSE) were entirely omitted as no cores from these individuals yielded datable material. The discarded cores exhibited extremely narrow rings or missing rings, which prevented unambiguous annual ring identification. In the case of the completely omitted trees, the rings were not fully visible in either core, likely due to internal decay, irregular growth, or suppressed cambial activity, which impeded reliable ring measurement. Such issues are commonly encountered in Mediterranean conifers, especially in older or physiologically stressed individuals, where irregular cambial activity, false rings, or growth discontinuities can compromise accurate measurement and cross-dating (De Micco et al. 2016). Table 2 shows the main

Table 2 Main parameters of the sampled trees. DBH: diameter at breast height. * One core at the base of the trunk was not taken for wood caries

Taxon	Area	n. of trees (n.cores)	n. of crossdated cores	Max time span	Min age (years)	Max age (years)	DBH span (cm)	DBH mean (cm)
Aesculus hippocastanum	AH	1	3 (8*)	8	92	150	45.9–57.0	51.3
Cedrus deodara	CD	3	3 (9)	9	86	94	86.6–94.9	91.8
Cupressus arizonica	CAR	1	3 (9)	7	52	73	52.5–77.1	62.3
Cupressus sempervirens	CSE	1–2	7 (21)	14	164	187	64.8–95.5	78.4
Pinus pinea	PP	2	1 (3)	3	140	140	93.0–93.0	93.0
Sequoia sempervirens	SS	3	4 (12)	10	81	91	109.2–150.0	123.0

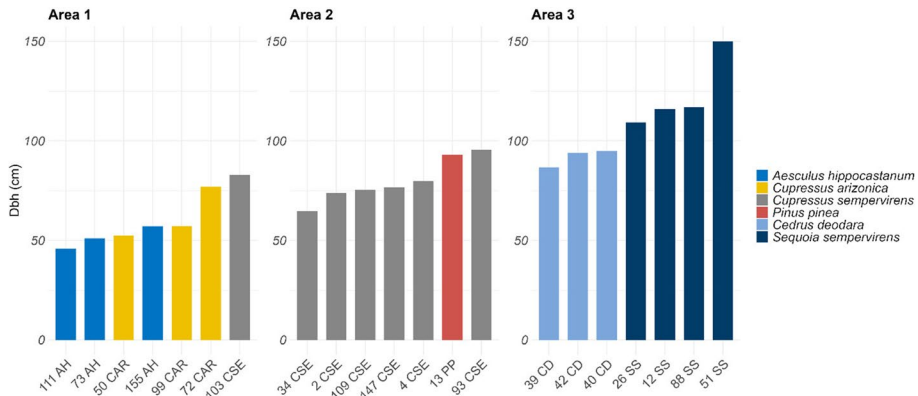


Fig. 4 Diameter at breast height (DBH, cm) in 2023 of each sampled tree. The X-axis number is the identification code for each tree according to Table 1

biometric parameters of the sampled trees, while Fig. 3 shows their diameters at breast height (DBH). The largest DBH value was 150 cm (51 SS, Area 3) and the smallest was 45.9 cm (tree 111 AH, Area 1). The trees with the largest DBH within each Area was: tree 103 CSE (82.8 cm) in Area 1, tree 93 CSE (95.5 cm) in Area 2 and tree 51 SS (150 cm) in Area 3. Among the taxa, *Sequoia sempervirens* had the highest mean DBH (123.0 cm), whereas *Aesculus hippocastanum* had the lowest (51.3 cm).

Figure 5 shows the location of the three oldest trees identified within each study Area. As can be observed, the oldest individuals are found in Areas 1 and 2 (182 and 187 years, respectively). In contrast, in Area 3 the corresponding trees are comparatively younger (94 years), reflecting the more recent establishment of the garden. Figure 6 shows tree-ring width series. In detail, in Area 1 the mean tree age was 108 years (SD 51 years), reflecting high variability across individuals (range 52–182 years). Tree 103 CSE was not only the oldest (182 years) but also had the largest diameter at breast height (DBH). Other mature individuals include 155 AH (148 years) and 73 AH (150 years). The youngest *Aesculus hippocastanum* individual was 111 AH (92 years), while the youngest trees in this area were the two CAR trees: 99 CAR (73 years) and 72 CAR (52 years).

In Area 2, the mean age was 171 years (SD 19 years), indicating comparatively low age variation. *Cupressus sempervirens* ranged from 164 years (93 CSE) to 187 years (109 CSE). *Pinus pinea* (13 PP) was 140 years old.

Finally, in Area 3, the mean age was 88 years (SD 4 years), consistent with a uniform age structure. The oldest tree was 42 CD (94 years), followed by 39 CD and 40 CD (both 86 years). The *Sequoia sempervirens* individuals were also close in age: 88 SS (91 years) and 51 SS (81 years).

Figure 7 shows the distribution of the earliest detectable age of trees, grouped by decades, across the three studied Areas. Notably, Area 1 exhibits the widest chronological range, with planting dates spanning from the 1840s to the 1970s. The distribution here reflects a high degree of temporal layering: the first quartile spans the period from 1840 to 1870, while the second quartile — also the most populated — extends from 1870 to 1930 and marks the median of the dataset, and this result suggests that a substantial number of trees were introduced during this central phase. The third quartile

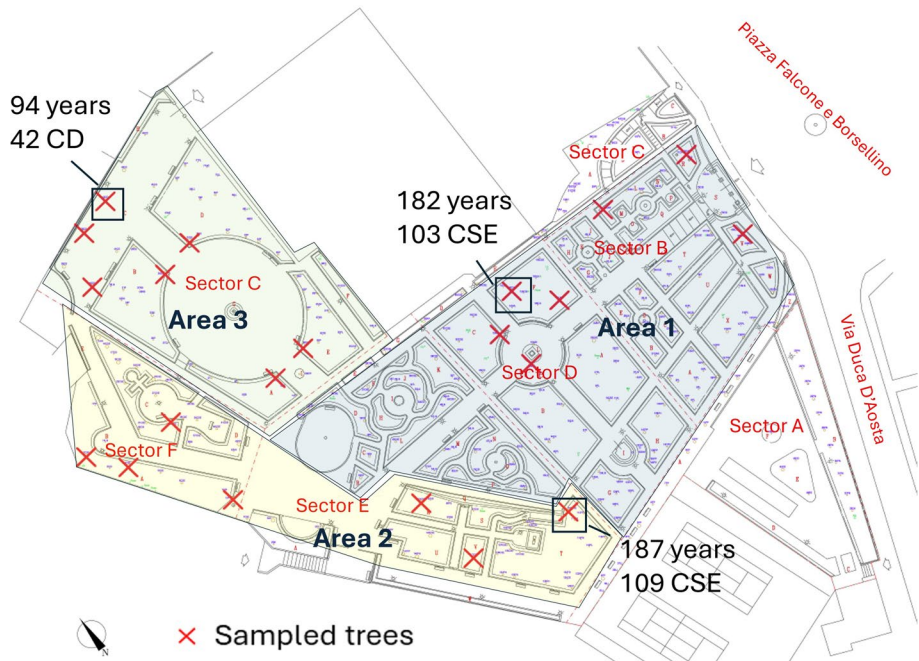


Fig. 5 Location of the oldest trees for each Area. CD=*Cedrus deodara*, CSE=*Cupressus sempervirens*

spans from 1930 to 1955, and the final quartile, comparatively narrow, includes only the years between 1955 and 1970.

In contrast, Area 2 presents a much more compressed temporal window, with all dated individuals falling between 1830 and 1880. The first two quartiles overlap significantly and cover the early part of this interval (1830–1840), indicating a likely single planting phase. The third quartile, which spans from 1840 to 1860, represents the core of the distribution. The final quartile, meanwhile, covers the period between 1860 and 1880.

Area 3 reveals the most temporally homogeneous distribution. All sampled individuals, except for one, are dated to the 1930s, suggesting a coordinated replanting event or major intervention during that decade. Only one tree (51SS) falls slightly outside this pattern, dating to the 1940s.

This chronological breakdown provides a clear overview of the distribution of planting periods in the three Areas, based on dendrochronological analysis.

Discussion

The combination of historical analysis and dendrochronological investigation proved essential for reconstructing the phases of the development of Villa De Capoa. As emphasized in the literature (Nestor and Mann 1998; Gullino et al. 2020), a comprehensive understanding of historic gardens requires both the analysis of archival documents and direct botanical and structural investigation. In this study, the combined use of dendrochronology and



Fig. 6 Individual tree-ring width series for each synchronised core. AH=*Aesculus hippocastanum*, CAR=*Cupressus arizonica*, CD=*Cedrus deodara*, CSE=*Cupressus sempervirens*, PP=*Pinus pinea*, SS=*Sequoia sempervirens*

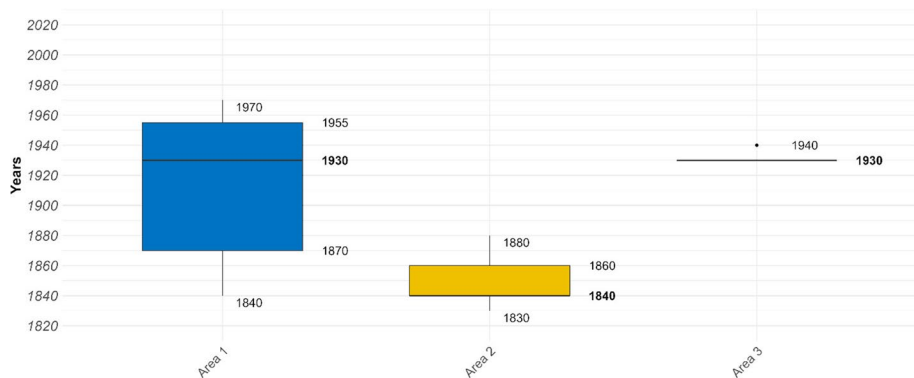


Fig. 7 Ten-year distribution of the first year recorded for trees by area of research

historical investigation allowed, through the creation of objective planting chronologies across tree species, the corroboration of the historical hypothesis investigated.

Area 1: A stratified planting history

The dendrochronological data from Area 1 indicate a heterogeneous age structure, with planting episodes occurring between the first half of the nineteenth century to the mid-twentieth century. The oldest tree in this area is a *Cupressus sempervirens* (103 CSE), dating back to 1842. This aligns closely with the hypothesized creation of the formal neoclassical garden, which, probably, Carlo De Capoa and Raffaella Salottolo commissioned in the first half of the nineteenth century and predates Antonio Pace's 1861 map. This map depicts a geometric garden layout that corresponds to the structure of Area 1. The presence of other *Cupressus sempervirens* and *Aesculus hippocastanum* specimens dating from the 1870s–1880s suggests a second primary planting phase, which may be linked to the donation of the villa to the orphanage by Marianna De Capoa (Salottolo) in 1877 and to Camillo Rosalba's proposals in 1880.

These results support the interpretation of Area 1 as a historically layered space, that has undergone progressive transformations over nearly a century. The presence of *Cupressus arizonica* (*Hesperocyparis arizonica* (Greene) Bartel Arizona and Mexico) trees dating from 1951 to 1972, provides further confirmation of 20th-century replanting events, which may be linked to documented urban landscaping initiatives between 1977 and 2002. This pattern suggests a progressive and prolonged planting process, a potential reflection of successive design modifications or restorations. Such stratification is common in historic urban gardens, where aesthetic and functional reconfigurations are often prompted by socio-political changes (Connell 2005; Matteini 2021).

Area 2: A coherent early planting phase

In contrast, Area 2 exhibits a coherent dendrochronological profile, with most trees dating to the period between 1830 and 1860. This includes some of the oldest specimens in the study, most notably a *Cupressus sempervirens* that is 187 years old and was established in 1837. This suggests that Area 2 was either part of the original neoclassical design or added as a contemporaneous extension. However, a second renovation phase occurred around 1860–1880, marking a significant transition in landscape design in Area 2. The outcome of these activities was the “picturesque” layout typical of landscape gardens as depicted on the map annexed to Camillo Rosalba's Drafting of a Master Plan for the city of Campobasso (1880). This shift from the symmetry and regularity characteristic of the Italian formal garden to a more irregular arrangement (Gothein 2014) is a clear evolution in the area's history.

Area 3: The rationalist phase of the 1930s

Area 3 is the youngest of the three areas and primarily comprises *Sequoia sempervirens* and *Cedrus deodara* (Roxb. ex (D.Don) G.Don trees which date back to the 1930s. Tree 51 SS, dated in 1940, is an exception, likely planted as a replacement following the death of an earlier tree. These results are consistent with historical documentation describing the municipal acquisition of the villa between 1930 and 1933, and its subsequent

conversion into the “*Villa Comunale del Littorio*”. The trees’ relatively uniform age (mean 88 ± 4 years) suggests a well-defined and likely municipally coordinated planting scheme, which is consistent with the rationalist ideals of urban green space design that were promoted during that period. This uniformity also signals a departure from the more ornate and eclectic compositions of the earlier phases, in favour of the monumental and symbolic species commonly employed in public gardens during the Fascist era to convey grandeur and stability (Cazzato 2022).

Management implications

The age structure across the three Areas reveals at least three major planting phases:

- (1) First half-19th century (c. 1830–1850): initial neoclassical layout, likely linked to wishes of the De Capoa family.
- (2) Late 19th century (c. 1870–1880): modifications associated with institutional transformation and urban planning.
- (3) Early 20th century (c. 1930s): redevelopment as a public garden under municipal administration during the Fascist period in Italy.
- (4) The sampled species arrived in Europe, including Italy, mainly as ornamental plants in noble villas. (Alan 1992). The origin of *Cupressus sempervirens* is uncertain. *Pinus pinea*, is considered to have an eastern Mediterranean provenience, likely introduced by the Etruscans or Phoenicians while *Aesculus hippocastanum* arrived from the Balkans in the 16th century. However, according to recent archeobotanical studies and reviews (D’Auria et al. 2019; Masi et al. 2021) the presence of taxa such as *Cupressus sempervirens* and *Pinus pinea* in Italy, dates back to the 15th century BC in central and northern Italy. This suggest an origin that predates the historically documented introductions. Species from other continents, *Cupressus arizonica*, *Sequoia sempervirens* (Pacific North America), and *Cedrus deodara* (Himalayas), were introduced in Tuscany around the mid-19th century and subsequently spread south, with records at the Royal Palace of Caserta and the Naples Botanical Garden by ~1890 (Orto Botanico di Napoli 1899; Iacono 2012), near Campobasso municipality. The stratified tree ages reinforce the concept of historic gardens as cultural palimpsests, in which each planting phase embodies shifting aesthetic, social, and political values (Connell 2005; Gothein 2014). The overlapping presence of species belonging to the genera *Cupressus*, *Aesculus*, and *Sequoia* not only indicates different periods of intervention but also reflects changing horticultural preferences: from classical and symmetrical to exotic and monumental plantings.

This study demonstrates the reliability of dendrochronology in clarifying the planting history of historic gardens, particularly where documentary evidence is fragmented or absent. Although similar methodologies have been applied in forestry (Motta and Lingua 2005; Garfi and Garfi 2024) and in the study of climate-vegetation interactions (Carrer and Urbinati 2004; Battipaglia et al. 2009), their application to the context of landscape heritage remains under-explored.

By identifying the most historically valuable trees (e.g., early nineteenth century *Cupressus sempervirens*), this approach supports evidence-based conservation planning and aligns with international guidelines that advocate for adaptive management of living heritage assets (ICOMOS-IFLA 2017). Precise dating of planting phases can help

prioritize preservation efforts, guide future replanting choices, and ensure continuity in the garden's historic identity and ecological integrity (Gullino et al. 2020).

Moreover, the findings respond to current environmental challenges. As climate change and urban pressures increase, historic gardens must not only preserve their cultural functions but also contribute to urban resilience and ecosystem service provision (Giles-Corti et al. 2016; Fineschi and Loreto 2020). From a conservation biology perspective, *Aesculus hippocastanum* is an endemic species of the Balkan Peninsula, currently occurring in the wild only as small, isolated populations. Consequently, it is classified as 'Vulnerable' at the European level (Rivers 2019) and is regarded as a taxon of conservation concern even beyond its natural distribution range. Species such as *Aesculus hippocastanum*, *Cedrus deodara*, and *Sequoia sempervirens* face a real and high risk of extinction, underscoring the need for firm conservation commitments from institutions and citizens alike. Consequently, individuals of these taxa require special attention in the planning and implementation of restoration measures at Villa De Capoa. In this sense, as highlighted by several studies, historic gardens play an important role in species conservation (Bartoli et al. 2024; Hosseini et al. 2024). Therefore, the 18 individuals of *Aesculus hippocastanum* trees growing in the Villa De Capoa, have the potential to contribute significantly to biodiversity preservation at the European level. The presence of highly allergenic plant species can have a significant impact on human health and the ecosystem services provided by urban and public green spaces. Therefore, it is advisable to prioritize the use of species with low allergenic potential, while closely monitoring ongoing research developments regarding allergenicity, cumulative exposure effects, and climate change-related interactions (Cariñanos and Mariñangeli 2021).

Conclusions

This study highlights the importance of organizing a multidisciplinary network of experts in a multidisciplinary approach, able to enhance the value of each component of the study in a complex mosaic of knowledge (Hosseini and Caneva 2022). In detail an interdisciplinary approach combining dendrochronology, botanic information and historical sources had permitted to reconstruct the development of Villa De Capoa, despite incomplete documentation. Tree-ring evidence identifies three main phases: (1) 1837–1850—a formal neo-classical layout consistent with the 1859–1861 map, with a compact cohort in Area 2 dominated by *Cupressus sempervirens*; (2) 1875–1880—replanting and reorganisation linked to Marianna De Capoa's bequest, with a heterogeneous Area 1 and *Aesculus hippocastanum* dated ca. 1874–1876; (3) the 1930s—homogeneous plantings of *Sequoia sempervirens* and *Cedrus deodara* and conversion to the "Villa Comunale del Littorio" (Area 3). Additional *Cupressus arizonica* dated 1951–1972 indicates further 20th-century interventions, likely tied to works undertaken between 1977 and 2002. Overall, Villa De Capoa emerges as a cultural palimpsest, with each phase reflecting distinct aesthetic and functional choices. Objective dating informs conservation planning—prioritization, replanting, and the continuity of historic identity and ecological integrity—while providing a transferable method for other historic gardens. In the context of climatic and urban pressures, the results underscore the role of sites such as Villa De Capoa as green infrastructure that delivers cultural value, conserves monumental trees as botanical heritage, and sustains ecosystem services and urban resilience.

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Data availability All data generated or analysed during this study are included in this published article and available under request to corresponding author.

Declarations

Disclosure statement No potential conflict of interest was reported by the author(s).

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