# Diversity and Spatial Distribution of Urban Heritage Tree Resources under Rapid Urbanization: Evidence from Anqing, China

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Heritage trees link natural ecosystems and cultural heritage, offering essential ecosystem services and embodying historical and community identity. This study investigated 318 heritage trees in Anqing City, southwest Anhui Province, China—a historically significant area undergoing rapid urbanization—through field surveys (June 2023 to October 2025), historical records, and spatial analysis. The trees comprise 50 species from 27 families, dominated by *Liquidambar formosana*, followed by *Camphora officinarum* and *Pterocarya stenoptera*. Species richness was highest in Yixiu District, while Daguan District showed the greatest diversity and evenness despite lowest abundance. Trees exhibited clustered distribution around temples, traditional villages, historical gardens, and institutional sites, reflecting cultural preferences and historical land use. Population structure skewed toward younger (74.5% aged 100 to 175 years) and moderate-sized trees, attributable to historical disturbances, recent protection policies, and urbanization impacts. Key threats include urban expansion, infrastructure damage, fragmented governance, inadequate maintenance, and climate change. The findings reveal the combined influence of ecological adaptability, cultural traditions, and anthropogenic factors on tree composition and distribution. Strengthened legal frameworks, scientific management, urban planning integration, community engagement, sustainable funding, and climate adaptation are needed. This work provides evidence-based recommendations for heritage tree protection in Anqing and insights for similar urbanizing regions in China.

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## INTRODUCTION

Urban heritage trees, typically exceeding a century in age and distinguished by their exceptional form, dimensions, and species rarity, serve as irreplaceable living monuments that bridge natural and cultural heritage (Blicharska and Mikusiński 2014; Jim 2017). These venerable trees function as keystone components of urban and rural ecosystems, providing critical habitat for diverse flora and fauna, stabilizing soil, enhancing water infiltration, and improving air quality through pollutant absorption and carbon sequestration (Lindenmayer 2017; Lai *et al.* 2020; Pretzsch *et al.* 2023). Beyond their ecological contributions, heritage trees embody profound cultural significance, serving as living witnesses to historical events, expressing community identity, and enriching the aesthetic character of landscapes (Suchocka *et al.* 2022; Parish 2025). Their presence fosters a sense of belonging among residents, contributes to mental well-being, and enhances property values and tourism potential (Donovan *et al.* 2024). As irreplaceable natural and cultural assets, heritage trees offer essential ecosystem services that cannot be replicated by artifacts, making their preservation fundamental to maintaining biodiversity, sustaining cultural heritage, and improving quality of life in both urban and rural environments.

The distribution and persistence of heritage trees are shaped by a complex interplay of ecological, environmental, and anthropogenic factors. Ecologically, species-specific traits such as growth rate, biological lifespan, stress tolerance, and resilience to disturbances determine which trees can attain heritage status (Liu *et al.* 2019, 2022). Environmental conditions including soil quality, topography, climate patterns—particularly precipitation and temperature regimes—play crucial roles in supporting tree longevity and vigor (Lindenmayer and Laurance 2017; Xie *et al.* 2022). However, human activities exert equally profound influences on heritage tree distribution. Historical and contemporary land-use practices, cultural customs, religious traditions, and conservation policies significantly affect which trees are planted, protected, and ultimately preserved across generations (Blicharska and Mikusiński 2014; Huang *et al.* 2023; Zhang and Grose 2025). Urban development patterns, agricultural practices, and socio-cultural values collectively determine the fate of these precious biological and cultural resources (Huang *et al.* 2020).

In China, heritage trees represent an invaluable component of both natural and cultural heritage, with particularly rich concentrations in historically significant regions (Pan *et al.* 2025). Recent research has increasingly focused on understanding the spatial distribution patterns and species diversity of urban heritage trees, revealing significant regional variations driven by both natural and social factors (Hou *et al.* 2022; Yang *et al.* 2024). Studies in North China cities such as Beijing have demonstrated that social factors predominantly influence large old tree distribution (Fu *et al.* 2022), while research in Qingdao has highlighted the disconnect between residents' socio-cultural valuation of heritage trees and policymakers' priorities, underscoring the need for multi-dimensional protection approaches (Zhang *et al.* 2019). However, despite growing recognition of heritage trees' multifaceted values, systematic investigations of their composition, distribution patterns, and conservation needs remain limited for many Chinese cities, particularly in regions experiencing rapid urbanization and socio-economic transformation.

Anqing, a historically and culturally significant city in Southwest Anhui Province, possesses a rich endowment of heritage trees nurtured through its extensive history and diverse landscape (Luo 2016). Located in a region characterized by complex topography spanning plains, hills, and mountains, and experiencing a humid subtropical monsoon climate, Anqing provides diverse habitats potentially favorable for heritage tree development. The city's long historical lineage has fostered cultural traditions of tree planting and protection, particularly around temples, ancestral halls, villages, and historical sites (Yin *et al.* 2025). However, like many Chinese cities, Anqing faces mounting pressures from rapid urbanization, infrastructure development, agricultural intensification, and climate change—factors that increasingly threaten the survival of its heritage tree population (Hu 2018; Xu 2019). Despite their ecological and cultural importance, heritage trees in Anqing have received limited systematic scientific attention (Cheng 2021). Previous studies have been fragmented and insufficient, lacking comprehensive assessment of species composition, spatial distribution patterns, diversity indices, and the environmental and anthropogenic factors driving these patterns. This knowledge gap significantly hinders the development of effective, evidence-based conservation strategies tailored to local conditions.

This study aimed to comprehensively investigate the heritage trees of Anqing, addressing critical knowledge gaps through systematic assessment of their species composition, diversity characteristics, spatial distribution patterns, and conservation challenges. Specifically, this research sought to answer four key questions: (a) What species of heritage trees are present in Anqing, and how do they vary in abundance and distribution across different districts and habitat types? (b) What environmental and socio-demographic factors influence the spatial distribution patterns of these trees? (c) What are the current conservation challenges and threats faced by heritage trees in Anqing? (d) What targeted conservation strategies can be recommended to improve their protection and ensure their persistence for future generations? By addressing these questions through rigorous field surveys, spatial analysis, and statistical modeling, this research aimed to provide a robust scientific foundation for heritage tree conservation planning in Anqing. The findings will not only inform local conservation policy and management practices but also contribute to the broader understanding of heritage tree ecology and conservation in rapidly urbanizing regions of China, offering insights applicable to similar cities facing the challenge of balancing development with natural and cultural heritage preservation.

## EXPERIMENTAL

### Study Area

Anqing (l29°47′ to 31°16′ N and 115°46′ to 117°44′ E) is a renowned historical and cultural city located in Southwest Anhui Province, China (Luo 2016). With a history spanning over 800 years as a prefecture-level administrative center, Anqing served as the provincial capital of Anhui for 267 years (1667 to 1934) and has been a vital political, economic, and cultural hub in the region. The city covers a total area of approximately 13,590 km², encompassing three urban districts (Yingjiang, Daguan, and Yixiu), one county-level city (Tongcheng), and seven counties (Huaining, Zongyang, Qianshan, Taihu, Susong, Wangjiang, and Yuexi). This study focused on the main urban districts in Anqing (Table 1).

The city experiences a humid subtropical monsoon climate characterized by four distinct seasons, abundant rainfall, and ample sunshine (Niu and Li 2020). The annual average temperature ranges from 14 to 17°C, with January mean temperatures of 3 to 4 °C and July mean temperatures of 27 to 29 °C. The annual precipitation averages 1,300 to 1,600 mm, with rainfall concentrated primarily during the spring and summer months (April to September), accounting for approximately 60 to 70% of annual precipitation. The frost-free period extends 237 to 266 days annually, and the region receives 1,800 to 2,200 hours of sunshine per year. These favorable climatic conditions, combined with fertile soils and adequate moisture, provide excellent environmental conditions for tree growth and longevity. The city’s rich historical legacy is reflected in its numerous cultural relics, including ancient temples, ancestral halls, traditional villages, and classical gardens, many of which harbor significant concentrations of heritage trees.

**Table 1**. Basic Urban and Tree Information of the Ten Districts in Anqing [a]

| District | Area ($km^2$) | Population | Urbanization rate (%) | Population density [b] (persons/$km^2$) | Forest cover (%) | Altitude (m) |
|---|---|---|---|---|---|---|
| Daguan | 204 | 23.8 | 83.2 | 1167 | 21.3 | 29 |
| Yixiu | 1276 | 17.48 | 86.4 | 137 | 40.8 | 49 |
| Yingjiang | 207 | 21.45 | 96.2 | 1036 | - | 38 |

[a] The information was mainly acquired from the official website of Anqing (https://tjj.anqing.gov.cn/) and Red & Black Population Database (https://www.hongheiku.com/);
[b] The population was based on 2024 data.

## Data Sources

Between June 2023 and October 2025, the authors conducted comprehensive field surveys of heritage trees throughout Anqing's administrative districts (Fig. 1). The multi-pronged data collection approach integrated: (1) systematic literature review of historical records, local chronicles, and previous botanical surveys; (2) acquisition of official data from municipal and county-level forestry departments and cultural heritage protection agencies; (3) exhaustive field investigations of trees and their surrounding habitats; and (4) interviews with local residents, temple custodians, village elders, and government officials to gather information on tree history, cultural significance, and management practices.

**Fig. 1.** Images of some typical specimens of heritage trees in Anqing. A denotes *Camphora officinarum*; B *Photinia serrulata*; C *Ligustrum lucidum*; D *Podocarpus macrophyllus*; E *Liquidambar formosana*; F *Osmanthus fragrans*

The assessment and measurement of heritage trees were conducted in accordance with the '*Technical Specifications for the Survey of Ancient and Famous Trees*' (LY/T 2738 to 2016) issued by the Forestry Industry Standards of the People's Republic of China (Pan *et al.* 2025; Xie *et al.* 2022). For each tree, precise geographic coordinates were recorded using a handheld GPS device (accuracy ≤ 5m), together with detailed habitat information, including site type, surrounding land use, and proximity to buildings or water bodies. Key morphological parameters, including diameter at breast height (DBH, measured at 1.3 m above ground), total tree height, crown width (calculated as the mean of the longest crown diameter and its perpendicular diameter), and height to the first major branch, were measured using a Brunei altimeter and measuring tape; for multi-stemmed individuals, all stems with DBH ⩾ 5cm were measured and documented separately. To avoid damage to these protected trees, invasive age-determination methods such as increment coring were not applied; instead, tree ages were derived primarily from official forestry census records, supplemented where necessary by interviews with long-term local residents, consultation of historical documents (*e.g.*, temple records and village chronicles), and comparison with dendrochronological data from conspecifics growing under similar environmental conditions. Species identification and scientific nomenclature were verified using the *Flora of China* database (http://www.iplant.cn/) and further confirmed by experienced botanists when required.

### Statistical Analyses

The importance value (IV) for each heritage tree species was calculated by integrating relative abundance (RA) and relative dominance (RD) (Jim and Zhang 2013). The formula is: IV = (RA + RD) × 100/2, where RA represents the number of individuals of a species divided by the total number of heritage trees in the study area, and RD is calculated as the total basal area at breast height of a species divided by the total basal area of all heritage trees in the study area. This composite index provides a comprehensive measure of each species' ecological significance within the heritage tree population. The Shannon–Wiener diversity index ($H'$) and species evenness index ($E$) were calculated using PAST 5.3 software (Hammer and Harper 2001). The evenness index was determined using the formula: $E = H'/\ln S$, where $H'$ is the Shannon–Wiener diversity index and $S$ is the total number of species. These indices collectively characterize the taxonomic diversity and distribution patterns of heritage tree communities across different districts and habitat types. QGIS Desktop version 3.34.0 was used to create spatial distribution maps showing the abundance of heritage trees across different administrative districts (Rosas-Chavoya *et al.* 2022).

## RESULTS AND DISCUSSION

### Species Composition and Importance Value

The comprehensive survey identified 318 heritage trees in Anqing, representing 50 species from 27 families and distributed across three protected tiers (Tier 1: >500 years, Tier 2: 300 to 499 years, and Tier 3: 100 to 299 years) (Table 2). This taxonomic composition showcases considerable botanical diversity characteristic of the humid subtropical transitional zone of Southwest Anhui Province.

The species distribution reveals marked dominance by a small cohort of species. *Liquidambar formosana* (Hamamelidaceae) overwhelmingly dominates with 88 trees (27.7% of total population) and an IV of 30.35, contributing a cumulative DBH of 6,960 cm. This species is predominantly represented in Tier 3 (86 trees), indicating relatively recent establishment or preferential preservation. Following are two co-dominant species: *Camphora officinarum* (Lauraceae) and *Pterocarya stenoptera* (Juglandaceae), each with identical IVs of 9.29, contributing 25 and 23 trees respectively. Together, these three dominant species account for 136 trees (42.8% of the population) and 48.9% of the aggregate IV, demonstrating their overwhelming ecological and structural significance.

**Table 2**. Indices Denoting the Quantity and Importance Value (IV) of the Main Heritage Tree Species in Anqing, Arranged in Descending Order of IV

| Species | Family | Tier 1 | Tier 2 | Tier 3 | Tree count | Cumulative DBH | IV |
|---|---|---|---|---|---|---|---|
| *Liquidambar formosana* | Hamamelidaceae | | 2 | 86 | 88 | 6960 | 30.35 |
| *Camphora officinarum* | Lauraceae | | | 25 | 25 | 2261 | 9.29 |
| *Pterocarya stenoptera* | Juglandaceae | | | 23 | 23 | 2392 | 9.29 |
| *Celtis sinensis* | Cannabaceae | | 1 | 24 | 25 | 1733 | 8.04 |
| *Ginkgo biloba* | Ginkgoaceae | | 2 | 21 | 23 | 1085 | 6.19 |
| *Juniperus chinensis* | Cupressaceae | | 3 | 7 | 10 | 470 | 2.69 |
| *Photinia serrulata* | Rosaceae | | | 9 | 9 | 463 | 2.51 |
| *Osmanthus fragrans* | Oleaceae | | 2 | 8 | 10 | 391 | 2.50 |
| *Gleditsia sinensis* | Leguminosae | 1 | 1 | 5 | 7 | 507 | 2.30 |
| *Xylosma racemosum* | Salicaceae | | | 9 | 9 | 346 | 2.23 |
| *Ilex cornuta* | Aquifoliaceae | | | 10 | 10 | 242 | 2.15 |
| *Ulmus pumila* | Ulmaceae | | | 7 | 7 | 437 | 2.14 |
| *Koelreuteria paniculata* | Sapindaceae | | | 7 | 7 | 307 | 1.83 |
| *Quercus chenii* | Fagaceae | | | 4 | 4 | 312 | 1.37 |
| *Ilex chinensis* | Aquifoliaceae | | | 5 | 5 | 214 | 1.29 |
| *Podocarpus macrophyllus* | Podocarpaceae | 1 | | 3 | 4 | 227 | 1.17 |
| *Diospyros kaki* | Ebenaceae | | | 4 | 4 | 174 | 1.04 |
| *Pistacia chinensis* | Anacardiaceae | | | 3 | 3 | 203 | 0.95 |
| *Cupressus funebris* | Cupressaceae | | | 3 | 3 | 191 | 0.92 |
| *Catalpa ovata* | Bignoniaceae | | | 3 | 3 | 181 | 0.90 |
| *Dalbergia sp.* | Leguminosae | | | 3 | 3 | 127 | 0.77 |
| *Quercus acutissima* | Fagaceae | | | 2 | 2 | 156 | 0.68 |
| *Triadica sebifera* | Euphorbiaceae | | | 2 | 2 | 143 | 0.65 |
| *Ulmus parvifolia* | Ulmaceae | | | 2 | 2 | 121 | 0.60 |
| *Magnolia grandiflora* | Magnoliaceae | | | 2 | 2 | 92 | 0.53 |
| *Acer buergerianum* | Sapindaceae | | | 2 | 2 | 78 | 0.50 |
| *Pseudocydonia sinensis* | Rosaceae | | | 2 | 2 | 69 | 0.48 |
| *Fontanesia philliraeoides* var. *fortunei* | Oleaceae | | | 2 | 2 | 48 | 0.43 |
| *Broussonetia papyrifera* | Moraceae | | | 1 | 1 | 83 | 0.36 |
| *Castanea henryi* | Fagaceae | | | 1 | 1 | 83 | 0.35 |
| *Styphnolobium japonicum* | Leguminosae | | | 1 | 1 | 83 | 0.35 |
| *Ailanthus altissima* | Simaroubaceae | | | 1 | 1 | 70 | 0.32 |
| *Ligustrum lucidum* | Oleaceae | | | 1 | 1 | 70 | 0.32 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Pinus massoniana* | Pinaceae | | | 1 | 1 | 67 | 0.32 |
| *Albizia julibrissin* | Leguminosae | | | 1 | 1 | 64 | 0.31 |
| *Fraxinus chinensis* | Oleaceae | | | 1 | 1 | 59 | 0.30 |
| *Bischofia polycarpa* | Phyllanthaceae | | | 1 | 1 | 57 | 0.29 |
| *Photinia davidsoniae* | Rosaceae | | | 1 | 1 | 57 | 0.29 |
| *Cedrus deodara* | Pinaceae | | | 1 | 1 | 54 | 0.29 |
| *Cyclobalanopsis myrsinifolia* | Fagaceae | | | 1 | 1 | 53 | 0.28 |
| *Cyclobalanopsis glauca* | Fagaceae | | | 1 | 1 | 51 | 0.28 |
| *Salix matsudana* | Salicaceae | | | 1 | 1 | 48 | 0.27 |
| *Magnolia soulangeana* | Magnoliaceae | | | 1 | 1 | 47 | 0.27 |
| *Prunus serrulata* | Rosaceae | | | 1 | 1 | 41 | 0.26 |
| *Ziziphus jujuba* | Rhamnaceae | | | 1 | 1 | 41 | 0.25 |
| *Citrus medica* | Rutaceae | | | 1 | 1 | 29 | 0.23 |
| *Citrus maxima* | Rutaceae | | | 1 | 1 | 26 | 0.22 |
| *Pteroceltis tatarinowii* | Cannabaceae | | | 1 | 1 | 25 | 0.22 |
| *Wisteria sinensis* | Magnoliaceae | | | 1 | 1 | 23 | 0.21 |
| *Citrus reticulata* | Rutaceae | | | 1 | 1 | 16 | 0.20 |
| Total | | 2 | 11 | 305 | 318 | 21078 | 100 |

The tree counts of species distributed in three age tiers (1 for >500 years, 2 for 300-499 years, and 3 for 100-299 years) are included.

*Celtis sinensis* (Cannabaceae) and *Ginkgo biloba* (Ginkgoaceae) emerge as prominent subdominants with 25 and 23 trees and IVs of 8.04 and 6.19 respectively. The top five species collectively comprise 184 trees (57.9%) and contribute 63.2% of the cumulative IV. The top ten species, including *Juniperus chinensis*, *Photinia serrulata*, *Osmanthus fragrans*, *Gleditsia sinensis*, and *Xylosma racemosum*, account for 219 trees (68.9%) and 69.3% of the aggregate IV. This markedly skewed distribution pattern indicates that relatively few species dominate the heritage tree landscape, reflecting their superior adaptability to local environmental conditions and sustained cultural preference over centuries.

The remaining 40 species exhibit substantially lower abundance, with individual counts of 1 to 10 trees and IVs below 2.15. Despite collectively contributing only 99 trees (31.1% of the population), these uncommon to rare species provide 80.0% of total species richness, considerably enriching the floristic diversity. Notable among these are species with ecological importance, relict species, and culturally significant species including traditional fruit trees (*Diospyros kaki*, *Ziziphus jujuba*, *Citrus* spp.) and ornamentals (*Magnolia* spp., *Prunus serrulata*, *Wisteria sinensis*).

The taxonomic composition reveals several families with multiple species representation, most notably Fagaceae (5 species), Oleaceae (4 species), Rosaceae (4 species), Leguminosae (4 species), and Sapindaceae (2 species). This diversity at the family level indicates varied ecological adaptations and multifaceted cultural utilization patterns that have shaped heritage tree selection and preservation across different historical periods and socio-cultural contexts in Anqing.

## Species Diversity and Spatial Differentiation

The spatial distribution of heritage trees across Anqing's three urban districts exhibits notable variations in abundance, species composition, and diversity indices (Table 3, Fig. 2 and Fig. 3). Yixiu District harbors the highest tree count with 195 individuals (61.3% of the total population), despite having the lowest tree density of 0.15 trees/km². This district also demonstrates the highest species richness with 32 species, indicating substantial floristic diversity. However, Yixiu exhibits a relatively low evenness index of 0.39, suggesting uneven species distribution dominated by a few abundant species. The Shannon diversity index of 2.52 reflects moderate overall diversity despite high species richness, further confirming the dominance of particular species within this district.

**Table 3**. The Frequency, Dimensions and Diversity of Heritage Trees in the Study Area Composed of Three Administrative Districts in Anqing

| District | Species count | Tree count | Density (tree/km$^2$) | Mean height (m) | Mean DBH (cm) | Mean canopy (m) | Shannon diversity | Evenness index |
|---|---|---|---|---|---|---|---|---|
| Daguan | 18 | 34 | 0.17 | 15.32 | 69.81 | 13.25 | 2.93 | 1.04 |
| Yixiu | 32 | 195 | 0.15 | 16.69 | 69.59 | 13.29 | 2.52 | 0.39 |
| Yingjiang | 25 | 89 | 0.43 | 12.51 | 57.68 | 10.83 | 2.72 | 0.61 |

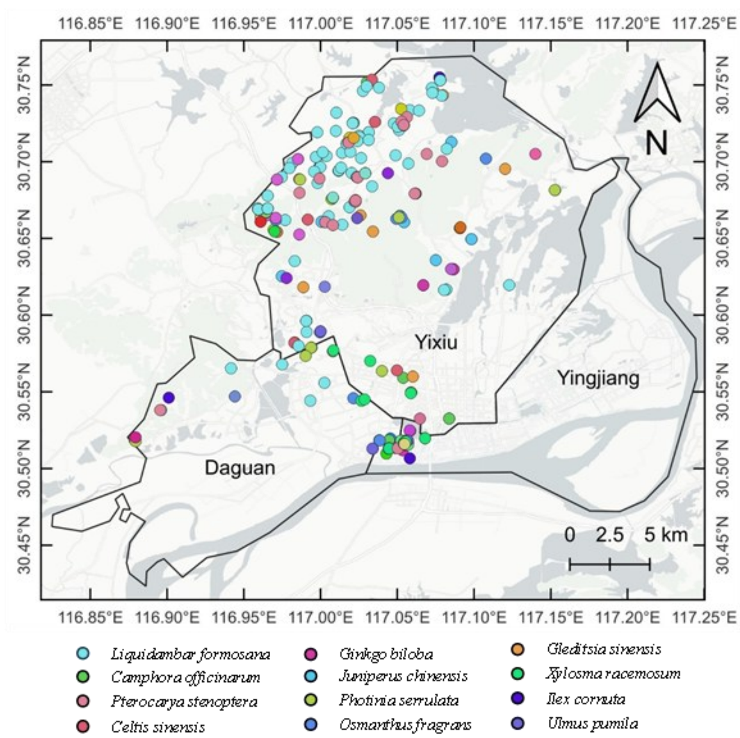


**Fig. 2.** Spatial patterns of heritage trees in Anqing. The legend beneath the main figure shows heritage trees with an importance value greater than 2.0 or a population size exceeding 10 individuals.

Yingjiang District, though containing only 89 trees (28.0% of the total), demonstrates the highest tree density at 0.43 trees/km², reflecting its more compact urban geography. This district supports 25 species with a Shannon diversity index of 2.72 and an evenness index of 0.61, indicating relatively balanced species distribution compared to Yixiu. The moderate evenness suggests that heritage trees in Yingjiang are more evenly distributed among species, with less pronounced dominance by any single taxon.

Daguan District has the smallest heritage tree population with only 34 individuals (10.7% of the total) and a tree density of 0.17 trees/km². Despite this limited abundance, Daguan supports 18 species and exhibits the highest Shannon diversity index (2.93) and evenness index (1.04) among the three districts. These indices indicate that heritage trees in Daguan are remarkably evenly distributed across species, with no pronounced dominance pattern. This high evenness, combined with substantial species richness relative to the small population size, suggests diverse historical planting practices and effective preservation of varied taxa.

The spatial mapping (Fig. 2 and Fig.3) reveals heterogeneous distribution patterns, with heritage trees clustered in specific areas rather than uniformly distributed. High-density grid cells are concentrated in particular zones within each district, likely corresponding to historical sites, temple grounds, traditional villages, and preserved green spaces. This clustered pattern reflects the influence of historical land use, cultural site preservation, and localized conservation efforts rather than systematic citywide distribution.

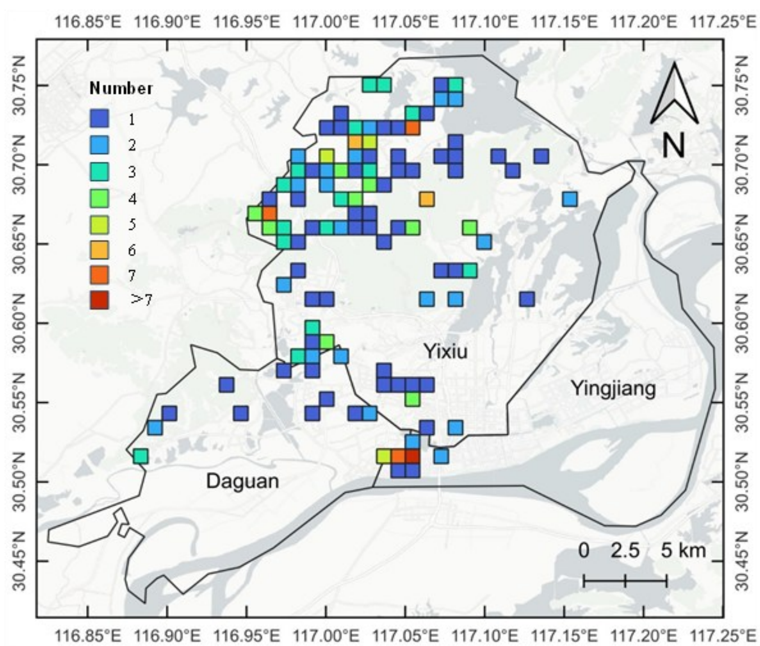


**Fig. 3.** Abundance of all heritage trees mapped in 1km×1km grid cells; the colors of the cells denote the number of heritage trees.

## Structure Characteristics

The structural attributes of heritage trees in Anqing, including diameter at breast height (DBH), height, crown width, and age, reveal distinct distribution patterns that provide insights into population dynamics and historical development (Fig. 4).

The DBH distribution exhibits a clear unimodal pattern with slight positive skew, ranging from 10 to 170 cm (Fig. 4a). The most abundant size class is 50 to 70 cm (29.6% of the population), followed by 70 to 90 cm (28.9%) and 90 to 110 cm (19.5%). These three dominant classes collectively account for 78.0% of all heritage trees, indicating that the majority possess medium to moderately large trunk dimensions. The polynomial regression curve ($y = -2.0947x^2 + 16.545x + 21.45$, $R^2 = 0.5291$; the tree count ($y$) is plotted against the DBH classes ($x$)) confirms the unimodal distribution with peak abundance in the 60 to 80 cm range. Trees decline sharply in both smaller (<50 cm, 15.4%) and larger (>110 cm, 6.6%) DBH classes, with only 6 individuals exceeding 130 cm. This pattern suggests limited representation of both young recruitment and exceptionally old, large-diameter specimens.

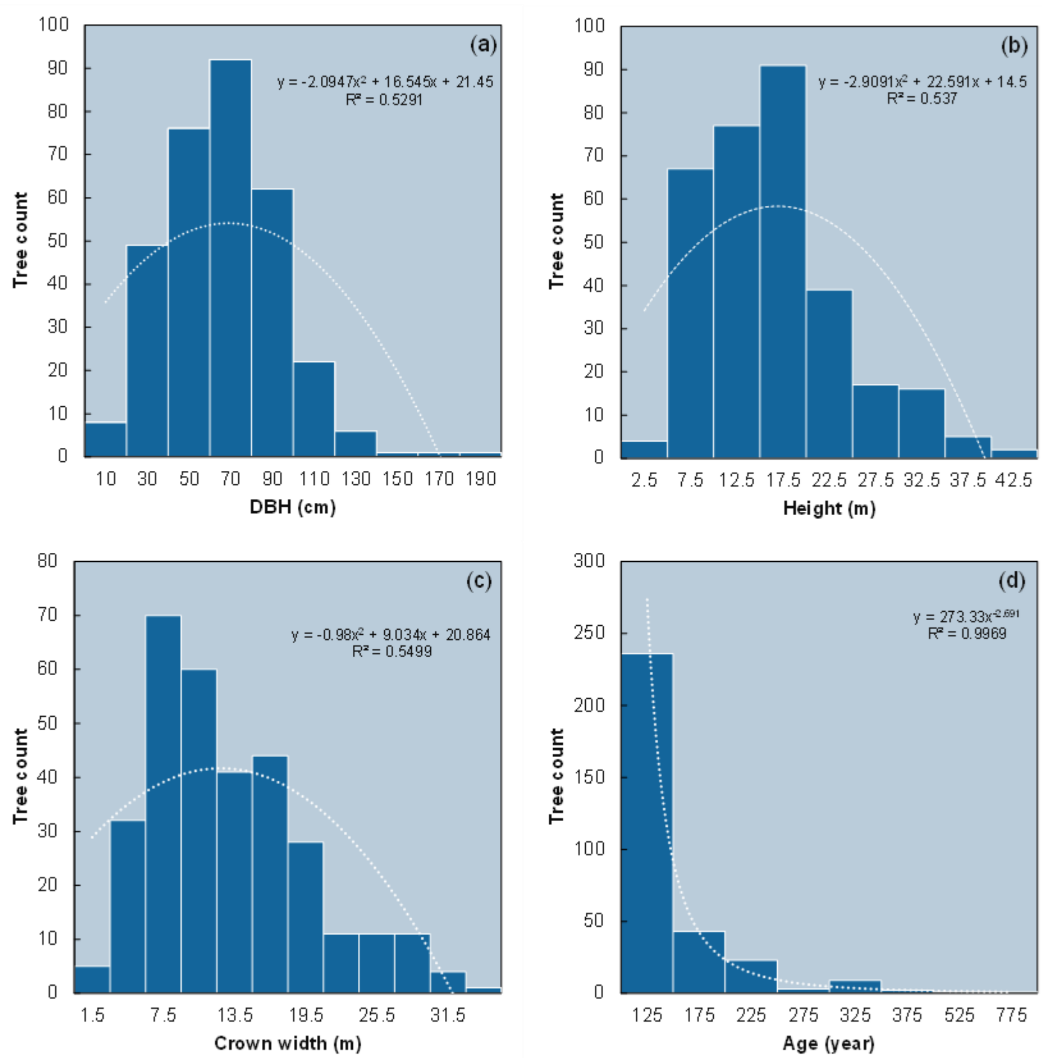


**Fig. 4.** Distribution of heritage trees by DBH (a), height (b), crown width (c) and tree age (d) in Anqing

The height distribution similarly displays a unimodal pattern with positive skew, spanning from 2.5 to 42.5 m (Fig. 4b). The predominant height class is 7.5 to 12.5 m (48.4%), followed by 12.5 to 17.5 m (28.3%) and 17.5 to 22.5 m (12.0%). These three classes encompass 88.68% of the population, indicating that most heritage trees are of moderate stature. The polynomial regression ($y = -2.9091x^2 + 22.591x + 14.5$, $R^2 = 0.637$) shows peak abundance around 10 to 15 m height. Trees become increasingly rare above 22.5 m (7.2%), with only 19 individuals exceeding 27.5 m. The scarcity of very tall trees

(>35 m, 2.2%) may reflect species composition dominated by moderate-statured taxa, growth constraints in urban environments, or management practices limiting vertical development.

The co-occurrence of peak DBH (50 to 70 cm) and peak height (7.5 to 13.5 m) suggests a general positive allometric relationship between trunk diameter and tree stature, broadly consistent with established scaling patterns tree populations (Karl 1995). However, substantial inter-specific and intra-specific variation in the DBH–height relationship—driven by differences in species growth forms, crown management, and site conditions—warrants dedicated allometric analysis in future studies.

Crown width distribution demonstrates a unimodal pattern extending from 1.5 to 34.5 m (Fig. 4c). The most abundant class is 7.5 to 13.5 m (41.5%), followed by 13.5 to 19.5 m (18.9%) and 19.5 to 25.5 m (14.2%). The polynomial regression ($y = -0.98x^2 + 9.034x + 20.864$, $R^2 = 0.5499$) indicates peak crown width around 10 to 15 m. Trees with narrow crowns (<7.5 m, 10.1%) and expansive crowns (>25.5 m, 5.7%) are relatively uncommon. This pattern reflects both intrinsic species characteristics and extrinsic factors such as growing space availability and pruning practices in urban and cultural heritage sites.

The age distribution reveals a striking exponential decline pattern (Fig. 4d), following the equation $y = 273.33x^{-2.691}$ ($R^2 = 0.9069$). The youngest age class (100 to 175 years) overwhelmingly dominates with 237 trees (74.5%), followed by 175 to 225 years (43 trees, 13.5%) and 225 to 275 years (20 trees, 6.3%). Trees older than 275 years become progressively rarer, with only 18 individuals (5.7%) exceeding this threshold. Notably, merely 2 trees (0.6%) surpass 500 years of age. It should be noted that while age, DBH, and height data are available for all surveyed trees, computing individual growth rates from these parameters is limited by the indirect nature of age estimation (based on historical records rather than dendrochronological coring) and the confounding effects of species composition differences among sites. A dedicated growth analysis incorporating direct age verification and species-stratified comparison across sites would substantially advance our understanding of how urbanization shapes heritage tree growth trajectories.

## Discussion

*Historical and cultural foundations of heritage tree development*

The heritage tree assemblage in Anqing represents a living botanical archive shaped by the city's profound historical legacy and cultural traditions spanning over eight centuries. As the provincial capital of Anhui for a long history, Anqing's administrative prominence created enabling conditions for cultivating and protecting exceptional trees through sustained resource accumulation and institutional stability. The city's historical role as a political, economic, and cultural center facilitated the establishment of elaborate government compounds, scholarly gardens, Buddhist and Taoist temples, ancestral halls, and elite residences—all traditional venues for heritage tree cultivation (Tceluiko 2019; Wan 2024). These institutional landscapes typically featured generous landscaping spaces with long-term management continuity, providing ideal conditions for trees to attain heritage status over generations.

The dominance of *L. formosana* (IV = 30.35, 88 trees) and *C. officinarum* (IV = 9.29, 25 trees) in Anqing's heritage tree flora reflects both ecological adaptability and deep-rooted cultural preferences. *L. formosana*, commonly known as Formosan sweet gum, has been extensively planted in southern China since ancient times for its spectacular autumn foliage, valuable timber, medicinal resin (storax), and symbolic association with scholarly elegance and natural beauty (Jiang *et al.* 2008). The species thrives in Anqing's humid subtropical climate with abundant rainfall (1,300 to 1,600 mm annually) and exhibits remarkable tolerance to the region's warm, moist summers and mild winters (Wang 2017). Its overwhelming representation in Tier 3 (86 of 88 trees aged 100 to 299 years) suggests intensified planting during the late Qing Dynasty and Republican period, coinciding with modernization efforts and expansion of urban green spaces (Luo 2016).

Similarly, *C. officinarum* (camphor tree) occupies a revered position in Chinese horticultural tradition, prized for its aromatic wood, medicinal properties, evergreen foliage, and cultural symbolism representing longevity and protection from evil spirits (Lin *et al.* 2021; Zhou and Yan 2016). Historically planted around temples, ancestral halls, and village entrances as guardian trees, camphor has been deeply embedded in local customs and feng shui practices (Liu *et al.* 2013). The co-dominance of *Pterocarya stenoptera* (IV=9.29, 23 trees), a riparian species naturally occurring along streams and riverbanks, likely reflects Anqing's distinctive geographic position along the Yangtze River and its extensive network of tributaries. This species' presence indicates deliberate preservation of native riparian forests or intentional planting to stabilize riverbanks and enhance waterfront aesthetics.

The notable representation of *Ginkgo biloba* (23 trees, IV=6.19), despite its moderate abundance, holds particular significance as a relict species endemic to China and globally recognized for conservation importance. Ginkgo has been cultivated in Chinese temple grounds and scholarly gardens for over a millennium, symbolizing resilience, longevity, and connection to ancient wisdom (Chen and Fan 2012). Its presence in Anqing predominantly around Buddhist temples, Confucian academies, and historical sites reflects sustained cultural reverence and institutional protection (Chen and Fan 2013). The diversity of traditional fruit trees—including *Diospyros kaki*, *Ziziphus jujuba*, and three Citrus species—documents historical agricultural practices and vernacular horticultural traditions (Cen *et al.* 2022; Sun and Sun 2022), particularly in rural villages and farmland habitats where these trees provided both sustenance and cultural continuity across generations.

*Spatial distribution patterns and urbanization impacts*

The pronounced spatial heterogeneity in heritage tree distribution across Anqing's three urban districts reveals the profound influence of urbanization gradients, historical land-use patterns, and differential conservation pressures (Le Roux *et al.* 2014). Yixiu District's dominance in both absolute abundance (195 trees, 61.3%) and species richness (32 species) can be attributed to its larger geographic extent, lower urbanization intensity in peripheral areas, and retention of historical villages, agricultural lands, and cultural heritage sites. However, its relatively low tree density (0.15 trees/km$^2$) and poor evenness ($E$=0.39) indicate that heritage trees are concentrated in specific locales—likely temple compounds, preserved traditional villages, and remnant agricultural landscapes—rather than uniformly distributed. This clustered pattern reflects historical planting traditions centered on culturally significant sites and the subsequent loss of trees from areas subjected to intense urban development (Huang *et al.* 2023; Yang *et al.* 2024).

Yingjiang District, despite having the smallest geographic area, exhibits the highest tree density (0.43 trees/km$^2$) and intermediate diversity (25 species, $H'$=2.72, $E$=0.61), suggesting more intensive historical tree planting and relatively successful retention within the compact urban core. This pattern likely reflects Yingjiang's role as Anqing's ancient administrative and cultural center, where concentrated institutional establishments—

government offices, academies, gardens, and temples—historically maintained elaborate landscaping traditions (Zhang and Grose 2025). The moderate evenness indicates more balanced species representation, possibly resulting from diverse institutional patrons with varied aesthetic preferences and functional requirements for different tree species.

Daguan District's remarkably high diversity indices ($H'$=2.93, $E$=1.04) despite minimal abundance (34 trees, 10.7%) represents a statistically intriguing pattern suggesting exceptionally balanced species distribution with no pronounced dominance. This may reflect several factors: (1) selective preservation of diverse specimens rather than mass plantings of favored species; (2) remnants of heterogeneous historical landscapes including mixed temple gardens, scholarly retreats, and residential courtyards; or (3) intensive urban development that has randomly eliminated trees, leaving behind a diverse but depleted remnant population. The district's larger mean tree dimensions (height 15.32 m, DBH 69.81 cm, canopy 13.25 m) despite small population size suggests that surviving trees occupy favorable microsites with adequate growing space and resources (Law *et al.* 2021).

The clustered spatial pattern revealed by grid-cell mapping underscores that heritage tree distribution in Anqing is fundamentally non-random, instead concentrating around specific historical and cultural nodes (Pan *et al.* 2025; Xie *et al.* 2022, 2024). High-density clusters correspond to: (1) ancient temple complexes and religious sites where trees receive spiritual veneration and institutional protection (Huang *et al.* 2025); (2) preserved traditional villages maintaining ancestral customs of tree worship and feng shui practices (Liu *et al.* 2013); (3) historical gardens and scenic areas where trees form integral components of designed landscapes; and (4) institutional grounds of former government offices, academies, and elite residences (Jim 2005). Conversely, areas subjected to intense modern urban development—including commercial districts, industrial zones, densely built residential areas, and major transportation corridors—exhibit conspicuous heritage tree deficits.

This spatial pattern reflects the broader challenge confronting heritage tree conservation in rapidly urbanizing Chinese cities: the fundamental incompatibility between compact, high-density urban development models, and the ecological requirements of large, old trees (Fröhlich *et al.* 2024). Modern urban planning typically prioritizes gray infrastructure (buildings, roads, utilities) over green infrastructure, resulting in limited soil volume, restricted aerial space, extensive impervious surfaces, and harsh micro-environmental conditions (heat island effects, pollution, compacted soils, limited water infiltration) that suppress tree vitality and longevity (Chen 2020; Le Roux *et al.* 2014). Heritage trees occluded within expanding urban fabrics face chronic stresses including root damage from construction, soil compaction from paving and pedestrian traffic, altered hydrology from drainage modifications, air pollution from vehicle emissions, and inadequate maintenance resources (Jim 2023; Moore *et al.* 2019).

Beyond tree composition, spatial variation in urban conditions likely generates differentiated growth trajectories among heritage trees across districts. Trees growing in the compact, high-density core of Yingjiang District may experience more pronounced growth restriction due to limited soil volume, impervious surfaces, and urban heat island effects, compared to those in the more rural periphery of Yixiu District. Future studies employing repeated dimensional measurements or dendrochronological analysis would be valuable to quantify how urbanization gradients modulate long-term growth rates of heritage tree populations.

*Population structure and temporal dynamics*

The population age structure of heritage trees in Anqing is markedly skewed toward younger cohorts, with 74.5% of individuals aged 100 to 175 years and only 0.6% exceeding 500 years. This configuration likely reflects the combined effects of historical disturbances, accelerated urban expansion, and biological constraints on tree longevity (Lüttge and Buckeridge 2023). Recurrent social and environmental disruptions during the late 19$^{th}$ and early 20$^{th}$ centuries, together with large-scale land conversion associated with rapid urban growth since the 1980s (Niu and Li 2020), may have resulted in substantial losses of older trees, leaving a limited legacy of very old individuals. In contrast, the pronounced concentration of trees in the 100 to 175 year age class corresponds with periods of increased planting linked to urban development, public landscaping, and institutional greening, further reinforced by contemporary conservation frameworks that recognize and register younger trees of ecological or historical significance. Superimposed on these human-driven processes, the steep exponential decline in older age classes reflects cumulative biological mortality arising from senescence, environmental stress, pests, and extreme events (Xie *et al.* 2025), while the dominance of moderately long-lived species such as *L. formosana* and *C. officinarum* inherently constrains the maximum attainable age of the population.

The dimensional distributions—exhibiting more balanced unimodal patterns for DBH, height, and crown width—contrast with the age distribution's exponential form. This discrepancy suggests that surviving heritage trees generally achieve moderate to large dimensions regardless of age, indicating adequate growing conditions and management for trees reaching protected status. However, the scarcity of exceptionally large specimens (DBH >130 cm: 1.9%; height >35 m: 2.2%; crown width >31.5 m: 0.9%) indicates ecological or management constraints limiting extreme dimensional development, possibly including: (1) space limitations in urban and institutional settings; (2) species composition dominated by moderate-statured taxa; (3) pruning practices constraining vertical and lateral growth; or (4) environmental stresses limiting vigor in urban contexts (Jim and Zhang 2013).

*Integrated conservation strategies and recommendations*

Heritage trees in Anqing are subject to increasingly complex and intensifying pressures arising from rapid urban expansion, uneven policy enforcement, limited public awareness, and the growing impacts of climate change (Gaur and Singh 2024). Although national and provincial regulations formally require the protection of heritage trees (Hou *et al.* 2022; Pan *et al.* 2025; Zhang *et al.* 2019), their practical implementation is often constrained by competing development priorities, insufficient administrative capacity, and fragmented governance across forestry, urban planning, and cultural heritage authorities. Addressing these challenges necessitates a holistic and integrated conservation framework that transcends sectoral boundaries. Effective safeguarding of Anqing's heritage trees should therefore combine strengthened policy coordination, science-based management, proactive spatial planning, enhanced community participation, and adaptive responses to environmental change. On this basis, the authors advance a set of targeted, evidence-informed recommendations to support long-term and resilient heritage tree conservation.

To effectively protect and manage Anqing's heritage trees, the city should first strengthen legal and institutional frameworks while integrating trees into urban planning (Xie and Jim 2025). This includes enacting strict municipal ordinances with clear penalties, establishing a dedicated Heritage Tree Management Office equipped with professional staff and budget, and mandating impact assessments for nearby developments (Lindenmayer and Laurance 2017). A transparent public registry with GIS-accessible data on tree locations, species, age, health, and cultural significance should be created (Nolan *et al.* 2020). Simultaneously, heritage trees must be incorporated as core constraints in city master plans and zoning (Suchocka *et al.* 2022), with designated protection zones around key specimens (especially in temples, historical gardens, and villages), green corridors for ecological connectivity, and biophilic design principles to accommodate large trees through setbacks, permeable surfaces, and structural soils.

The question of whether heritage trees continue to produce viable offspring under current urban conditions—and whether natural seedling recruitment is feasible in Anqing's highly impervious and managed urban matrix—merits dedicated investigation. Observational evidence from comparable cities suggests that natural regeneration from large old trees is severely curtailed in dense urban settings by impervious surfaces, active ground management, and lack of suitable microsites (Chen 2020; Le Roux *et al*. 2014). Monitoring natural recruitment and, where necessary, supplementing it through ex-situ propagation and strategic replanting should therefore be incorporated into Anqing's long-term heritage tree management plan.

Scientific management and advanced technology are essential for long-term preservation. Standardized protocols should involve annual health assessments by certified arborists, tailored care plans (pruning, fertilization, pest control, soil improvement), protective infrastructure, and detailed individual tree records (Clark and Matheny 1991). GIS technology should be expanded into a comprehensive information system for spatial analysis, vulnerability mapping, real-time monitoring, and identifying sites for new plantings (Denghua *et al.* 2018). Climate adaptation strategies are critical, including modeling impacts on species, assisted measures like irrigation and mulching, potential relocation for stressed trees, and diversifying future plantings with resilient species that retain cultural and ecological value.

Community engagement, sustainable funding, and research will ensure ongoing success (Nolan *et al.* 2020). Programs such as "Heritage Tree Guardians," mobile apps for citizen monitoring, educational initiatives, and awards can foster public stewardship and awareness. Funding mechanisms should include a dedicated conservation fund from municipal budgets, donations, sponsorships, eco-tourism, payments for ecosystem services, and incentives for developers. Partnerships with universities for ecological research, long-term monitoring, and dendrochronological studies will refine strategies. Finally, Anqing should draw lessons from successful models in cities such as Hong Kong (Jim and Zhang 2013), Beijing (Fu *et al.* 2022), and European networks, adapting proven approaches to its unique historical, cultural, and ecological context.

Beyond regulatory enforcement, fostering broad public appreciation of heritage trees as economic and cultural assets represents a powerful mechanism for aligning developer incentives with conservation goals. Empirical studies demonstrate that the presence of urban trees is associated with measurable property value premiums (Escobedo *et al*. 2015), suggesting that heritage trees can be reframed from a development constraint into a marketable asset that attracts buyers and tenants willing to pay for green amenity. If urban developers, property owners, and the wider public come to regard heritage tree preservation as enhancing rather than limiting the value of their properties, conservation-compatible design solutions—such as tree-integrated building setbacks, permeable paving, and heritage tree feature plazas—are more likely to be voluntarily adopted. Public education campaigns, developer recognition schemes, and heritage-tree-sensitive real estate marketing therefore constitute important complementary strategies to regulatory frameworks.

## CONCLUSIONS

1. Anqing's heritage trees constitute a botanically diverse yet structurally imbalanced population, characterized by strong dominance of a few species (notably *Liquidambar formosana*, *Camphora officinarum*, and *Platanus stenoptera*), reflecting the combined effects of ecological suitability, regional climate, and long-standing cultural preferences.
2. The spatial distribution of heritage trees is highly heterogeneous, with clear clustering around temples, traditional villages, historical gardens, and institutional sites, demonstrating that cultural and historical drivers have played a more decisive role than biophysical factors in shaping preservation patterns.
3. Population age structure is markedly skewed toward younger cohorts, suggesting either substantial historical losses due to wars, political disruptions, and urban expansion, or a pronounced increase in recent conservation and designation efforts associated with modernization.
4. Heritage trees in Anqing face escalating pressures from urban development, exemplifying a widespread challenge in rapidly urbanizing regions of China; nevertheless, this study provides a critical empirical baseline to support evidence-based conservation and highlights heritage trees as living embodiments of Ecological Civilization, essential for sustaining both cultural continuity and urban ecological resilience.

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### Conflict of Interest

The authors have no relevant financial or non-financial interests to disclose.

### Use of Generative AI

The authors used DeepSeek solely for language polishing and stylistic refinement of the manuscript. No generative AI tools were used for data analysis, interpretation, image or figure preparation, or the generation of scientific content.

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