Number and distribution of large old ginkgos in east China: Implications for regional conservation

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Abstract

Large old ginkgos (LOGs), having important ecological, cultural and historical values, are widely distributed in China. However, little is known regarding their quantity and tree-habitat quality in the mesoscale distribution. Here, the quantity, spatial distribution and conservation status of *Ginkgo biloba* L. older than 100 years in Jiangsu Province, east China were examined using ArcGIS software and detrended correspondence analysis (DCA). Based on our collated data, Jiangsu Province included 2,123 LOG individuals and 237 LOG groves and both mostly occurred in southern and central Jiangsu. Most LOGs grew well and were distributed in villages, temples and government institutions. Ginkgos’ growth status was largely associated with tree-habitat types. LOGs performed worse in commercial areas, roadsides and residential districts than in other tree-habitat types. To protect these ginkgos, dynamic monitoring and strengthening of scientific management are required, especially for tree-habitats in the process of urban planning and construction. It is also necessary to improve the relationship between religious culture and conservation measures. This is the first study examining LOGs in Jiangsu Province using a unified standard and our findings provide a baseline for future studies and insights into the regional conservation of LOGs.

Keywords

Abundance, ancient tree, *Ginkgo biloba*, spatial distribution, tree-habitat conservation, urbanisation impact
**Introduction**

Large old trees play significant roles in the ecosystem and biodiversity. They provide shelters for animals, store a large quantity of carbon and create microhabitats for organisms (Lindenmayer et al. 2012; Nolan et al. 2020). At present, research on the distribution, survival and conservation of large old trees has been carried out in many regions around the world (Aerts 2013; Mahmoud et al. 2015; Lindenmayer and Laurance 2016; Mölder et al. 2020).

_Ginkgo biloba_ L. is one of the most common ancient trees across China (Fu et al. 2014; Zhu et al. 2019; Liu et al. 2020). _Ginkgo biloba_, endemic to China, is a long-lived deciduous tree (Tredici 2007), whose seeds have been used as food and medicine for thousands of years. Ginkgos have been cultivated in China since 1273 (i.e. Song Dynasty) (Crane 2016). _Ginkgo biloba_ is cultivated in 32 Provinces across China, ranging from 50°10’N to 22°51’N, from 127°00’E to 121°30’E. Nowadays, a large number of old trees of this species are scattered in 23 Provinces across China, with an age over 100 years old (Xing 2013). Most large old ginkgos (LOGs) are distributed in the eastern and central subtropical China (Cao 2007).

Current studies on LOGs mainly focus on its origin, evolution and genetic diversity. Both ecological and molecular evidence indicate that Tianmu Mountains, Zhejiang Province, hold wild populations of ginkgos (Tredici et al. 1992; Li et al. 2011). Zhao et al. (2019) identified three refugia in China by re-sequencing _Ginkgo_ genomes across the world and pointed out that anthropogenic introductions resulted in the spread of ginkgos from eastern China to other countries. A multi-feature analysis of ginkgo vascular cambial cells found that old ginkgos include a high expression of disease resistance-related genes, which may lead to its longevity (Wang et al. 2020). However, little is known about the population and conservation ecology of LOGs (Chi et al. 2020). Most current studies have been confined to a small area and researchers only made a simple description of ginkgos including their number, the diameter at breast height (DBH) and tree height due to a lack of uniform criteria or survey standards. Accordingly, it is difficult to compare these survey data retrieved from different regions.

Here, we selected Jiangsu Province in east China, as a representative sampling site to examine its spatial distribution and appraise its conservation status. With a history of more than 2,500 years, Jiangsu Province has two of the six counties called “Ginkgo Village” around the country (i.e. Taixing and Pixian). Moreover, the seed production of _Ginkgo biloba_ in Jiangsu Province ranks first nationwide for the past few decades. For example, in Taixing, annually 4,000 tonnes of ginkgo nuts are produced, accounting for approximately one-third of the country’s total output (personal communication, data from Jiangsu Forestry Bureau).

In this study, we compiled a dataset of LOGs, including the number, distribution and growth status for the first time at the provincial level in China. Moreover, we analysed the relationship between tree-habitat types and growth status and then explained the effect of local culture and history on the growth of LOGs. Each sample of ginkgos was more than 100 years old. Specifically, the three objectives of this study are:
1. to map the spatial distribution of LOGs across Jiangsu Province (i.e. southern, central and northern Jiangsu) and their distribution in three protection categories;
2. to analyse DBH size class distributions of LOGs in the three Regions of Jiangsu Province;
3. to characterize the growth status of these LOGs and to determine underlying factors affecting their growth and conservation.

The purpose of this study is to address the quantity, distribution and growth characteristics of LOGs in east China and to provide implications for regional conservation and management.

**Methods**

**Study area**

The study area, Jiangsu Province (30°45’N–35°07’N, 116°22’E–121°55’E), has a long cultivation history of *Ginkgo biloba*. It is located in the centre of the eastern coast of mainland China. This Province covers 107,200 km² and has a coastline of over 1,000 km along the Yellow Sea. Geographically, Jiangsu Province can be divided into southern (S. Jiangsu), central (C. Jiangsu) and northern (N. Jiangsu).

The climate of Jiangsu Province ranges from temperate to subtropical. N. Jiangsu has a warm temperate humid monsoon climate, while S. Jiangsu and C. Jiangsu have a subtropical humid monsoon climate. The annual mean temperature in the Province is 13–16 °C. Jiangsu accommodates many rivers and lakes and the mean annual precipitation of Jiangsu is 998.5 mm. The terrain is mainly flat and the highest altitude is 624.4 m. There are several soil types from northern to southern Jiangsu which are, namely, brown soil, leached cinnamon soil, yellow-brown soil and red-yellow soil (Jiangsu Forestry Bureau 2017).

**Data collection**

An inventory of Forest Genetic Resources, including ancient trees, was carried out from 2016 to 2020 in Jiangsu Province. The standard of large old trees followed “Technical Guidelines for Document Establishment of General Survey of National Ancient-Famous Trees” of 2001 in China. In this guideline, ancient trees are divided into three protection categories: 100 years ≤ tier 3 ≤ 299 years, 300 ≤ tier 2 ≤ 499 years and tier 1 ≥ 500 years. The information of each ancient tree in the territory, including global positioning system (GPS) coordinates, DBH, tree age, growth status and photographs were transferred to the Cloud Platform for Forest Genetic Resources Information of Jiangsu Province (with restricted access).

In this study, all records of LOGs in Jiangsu Province were downloaded from the platform and processed by the following standards: (1) *Ginkgo biloba* with DBH < 50 cm was
eliminated (Zhu et al. 2019). (2) Incorrect or questionable data (e.g. DBH > 7,000 cm) was re-investigated and corrected. (3) The growth status of ginkgos was classified as good, fair, poor and dying. The good category implies that the ginkgo is vigorous and without interference. The fair category means the ginkgo has an average growth performance, as well as minor damage and interference. The poor category means the ginkgo is weak, growing slowly and suffering serious damage. The dying category indicates the ginkgo is moribund and whose branches are mostly withered (Zhang et al. 2017). (4) Nine tree-habitat types were identified from field records and tree owners (Table 1).

### Data analysis

Based on GPS coordinates, the distribution map of LOGs in Jiangsu Province was prepared using ArcGIS 10.1 (Fig. 1). Differences amongst the three Regions of Jiangsu can be directly shown in this distribution map.

Size classes of DBH were used in this study, which is similar to age classes (Silvertown and Charlesworth 2003), because size classes of DBH and age classes of a tree can consistently respond to the environment (Frost and Rydin 2000; Li and Zhang 2015). LOGs in Jiangsu Province mainly exist in the form of individuals rather than groves. Most individuals sporadically occur in Jiangsu Province and are less likely to be managed and protected, thus making them exist in a semi-natural state. Accordingly, these LOG individuals over hundreds of years old are commonly different from trees in a plantation.

Here, we divided all LOG individuals in each Region into various groups by size classes of DBH in order to analyse their distribution. The metrics 50–70 cm stand for the first class (I) and the size class increases by one with each 20 cm increase in DBH.

**Table 1.** The nine tree-habitat types which accommodate LOGs in Jiangsu Province, east China.

| Abbreviation | Tree-habitat types | Paraphrase                                                                                           |
|--------------|-------------------|------------------------------------------------------------------------------------------------------|
| VF           | Villages and farmlands | Including rural areas and farmlands where houses are low and far from the city centre with small population density, usually surrounded by croplands. |
| RC           | Religious sites and cemeteries | Including ancestral temples, Taoist temples, nunneries, memorial parks which are mostly associated with the sacrificial activities of ancestors and gods. |
| GC           | Government, institutional units and community grounds | Including schools, hospitals, libraries, museums, retirement homes and military regions which are usually non-profit institutional units directly managed by the State. |
| EC           | Enterprises and commerce places | Including factories, supermarkets and business towers which are usually places for commercial activities to generate revenue. |
| RD           | Residential districts | Including residential quarters and apartments where buildings are compact and close to the city centre with large population density, usually surrounded by shops and entertainment venues. |
| PG           | Parks and gardens | Including public parks, forest parks, street gardens, botanical gardens and historical sites which often aim to provide a good ecological environment. |
| WP           | Wooded areas and plant nurseries | Including firewood farms, arboretums and fruit ranches that are dedicated to the cultivation and tending of trees. |
| RS           | Roadsides | Including pedestrian lanes, isolation belts and traffic circles where trees are often near the main roads directly monitored by the city virescence management office. |
| OT           | Others | Including all sites that are not well-described or fail to fall into the other eight categories, such as ferry stations, golf courses and well fields. |
(II–XV). In general, a certain range of DBH represents a corresponding range of tree ages. Hence, we also divided these LOGs into the following three categories: 50 cm ≤ tier 3 < 90 cm, 90 cm ≤ tier 2 < 130 cm and tier 1 ≥ 130 cm. By doing so, they can correspond to the three protection categories of national ancient-famous trees in China.

To better understand the conservation status of LOGs across different tree-habitat types, a three-dimension graph of ginkgo performance in nine habitat types in Jiangsu Province was drawn using Origin 2019 and detrended correspondence analysis (DCA) was performed using Canoco v5.02 to further reveal the relationship between the growth status and tree-habitat types (Zhang et al. 2017; Huang et al. 2020).

**Results**

**Spatial geographical distribution**

We compiled a dataset of 2,123 LOG individuals and 237 groves across 13 prefecture-level cities in Jiangsu Province, China (Fig. 1, Suppl. material 1). Regarding LOG
individuals, their distribution was uneven and mostly occurred on both sides of the Lower Yangtze River Basin in Jiangsu Province. Moreover, there were more ginkgos in S. Jiangsu (48.42%) and C. Jiangsu (38.48%) than in N. Jiangsu (13.10%), although N. Jiangsu has the largest administrative area. In addition, amongst these 13 cities, LOG groves were only found in Taizhou and Xuzhou (mainly in Taizhou). Accordingly, most LOGs occurred in the form of individuals rather than groves in Jiangsu Province.

**DBH size class distribution**

We divided 2,123 LOG individuals into 15 size classes, amongst which the first four (I–IV) size classes contained most of the individuals (Fig. 2). We found that the number of size classes in C. Jiangsu and N. Jiangsu was smaller than that in S. Jiangsu (Fig. 2a–c). In addition, there were more super-aged senior LOGs in S. Jiangsu than in C. or N. Jiangsu.

More than 60% of LOGs were classified as third-class (tier 3) ginkgos in Jiangsu Province (Table 2). Amongst these ginkgos, 43.51% were in C. Jiangsu and 41.71% in S. Jiangsu. Regarding the second-class (tier 2) ginkgos, more than half occurred in S. Jiangsu. Finally, the first-class (tier 1) ginkgos were always the fewest in each Region, amongst which S. Jiangsu included 218 ancient trees accounting for 74.15% of the total first-class LOGs.

**Growth status**

We also explored the relationship between tree-habitat types and the growth status of LOG individuals in Jiangsu Province (Fig. 3). Fig. 3a illustrates the relative quantitative differences, while Fig. 3b explores the relationship between tree-habitat types and the growth status of those ginkgos.

More than 85% of the LOGs grew well (Suppl. material 1). Amongst them, 50.31% of the growth status was fair with the largest proportion, followed by the good status accounting for 34.95%. This result indicated that most ginkgos in Jiangsu Province were well preserved. Regarding the nine tree-habitat types (see Table 1 for the specific definitions), most LOGs were distributed in VF, RC, and GC, accounting for 39.10%, 21.06%, and 17.15%, respectively. Moreover, the percentage of these ginkgos grown in VF was always the largest in each growth status type.

LOGs in a good growth status were close to all these nine tree-habitat types (Fig. 3), indicating that the frequency of their occurrences in each tree-habitat type was high and relatively similar. Ginkgos in a fair growth status were closest to WP, meaning that the frequency of their appearance in WP was higher than those in other tree-habitat types. Dissimilar to ginkgos in better conditions (i.e. good and fair), those in a poor growth status were the closest to RD and RS and the dying ones were the closest to EC. Ginkgos in worse conditions gained a higher probability to grow in EC, RD or RS, implying that these three tree-habitat types were less suitable for the survival of LOGs in Jiangsu Province, China.
Table 2. The number of LOG individuals classified by DBH size classes in three Regions of Jiangsu Province.

| Class of ginkgos | DBH (cm) | Size classes | S. Jiangsu | C. Jiangsu | N. Jiangsu | Subtotal |
|------------------|----------|--------------|------------|------------|------------|----------|
|                  | Number   | %            | Number     | %          | Number     | %        |
| Third-class      |          |              |            |            |            |          |
| 50–90            | 601      | 58.46        | 627        | 76.74      | 213        | 76.62    | 1441     | 67.88    |
| Second-class     | 209      | 20.33        | 135        | 16.52      | 44         | 15.83    | 388      | 18.28    |
| First-class      | 218      | 21.21        | 55         | 6.73       | 21         | 7.55     | 294      | 13.85    |
| Total            | 1028     | 100.00       | 817        | 100.00     | 278        | 100.00   | 2123     | 100.00   |

Discussion

Quantity and distribution of LOGs

Ginkgo biloba, a relic of the Tertiary period, are now rare in the wild, whereas the long cultivation history of ginkgos has made it one of the most common cultivated trees, widely distributed in 32 provinces, autonomous regions and municipalities across China (Guo et al. 2019). The vast majority of LOGs in Jiangsu Province derive from artificial cultivation according to field records and our survey.
Figure 3. The growth status of LOGs across different tree-habitat types in Jiangsu Province (see Table 1 for the explanation of abbreviated habitat types) a three-dimension graph of the number of ginkgos across nine tree-habitat types b detrended correspondence analysis of the relationship between tree-habitat types and growth status with the cumulative explained variation as 78.71%. Tree-habitat types and growth status are drawn as stars and triangles, respectively.
Here, we sorted out reliable information of 2,123 LOG individuals and 237 LOG groves in Jiangsu Province for the first time. This is markedly different from previous survey data of LOGs. Only 77 LOGs with tree height and DBH were listed in a retrospective monograph titled “Ginkgo in China” (Cao 2007). Nevertheless, Fu et al. (2014) supposed that there were 11,858 LOGs in Jiangsu Province, amongst which only 632 had partial growth indices, such as DBH. Liu et al. (2019a) counted a total of 836 LOGs through reports and documents, while the data sources only involved several prefectural-level cities in Jiangsu Province. Possible reasons for such differences are chiefly as follows: (1) Inconsistent survey methods. For example, we set the starting DBH of 50 cm in our survey (Zhu et al. 2019). However, the survey criteria used in other studies were either different from ours or not stated. (2) Different degrees of investigation. Our survey was based on a census of field investigation from 2016 to 2020, but the actual investigation degree and scope in other studies may be much shorter than ours. Therefore, our study can be used as a baseline for the protection and management of LOGs in Jiangsu Province.

Our findings indicate that there were more LOGs in S. Jiangsu and C. Jiangsu and most of the first-class ginkgos were distributed in S. Jiangsu (Figs 1, 2 and Table 2). Such differences can be mainly attributed to two factors: (1) Climate differences. The mean annual precipitation and temperature in S. and C. Jiangsu are higher than those in N. Jiangsu. Many large old trees are sensitive to drought and persistent to high temperatures (Bennett et al. 2015; Lindenmayer et al. 2016; Venter et al. 2017; Choat et al. 2018). Regarding tall LOGs with strong root stems, their evaporation and water requirement are relatively high and, therefore, the subtropical humid monsoon climate in S. and C. Jiangsu is more suitable for ginkgos to survive than in N. Jiangsu. (2) Soil differences. There are almost no coastal cities in S. and C. Jiangsu (except Nantong) (Fig. 1). However, both Yancheng and Lianyungang in N. Jiangsu have a much longer coastline than Nantong has in C. Jiangsu. In these coastal areas, a narrow saline belt extends from north to south, where the soil has a salt content of 1–4% (Jiangsu Forestry Bureau 2017). When the salt content in soil increases to more than 0.3%, it can pose a fatal threat to the growth of ginkgos (He et al. 1997). This factor can explain that almost no LOGs can be found near coastal areas. In contrast, S. Jiangsu is on the southern bank of the Lower Yangtze River. In alluvial plains along rivers and lakes, humus and soil layers are thick and rich in nutrients such as calcium, magnesium, potassium and phosphorus (He et al. 1995), which are suitable for the growth of LOGs. Liu et al. (2020) found that the first-class ancient trees were mostly distributed in southeast Anhui Province, especially to the south of the Yangtze River. This result is also consistent with the distribution of the first-class ginkgos in Jiangsu Province according to our analysis. Besides, in terms of financial development, S. Jiangsu is the best, followed by C. Jiangsu and N. Jiangsu is the third in the past few decades. Additionally, S. Jiangsu has a longer cultural history than the other parts of Jiangsu Province.

In short, climate and soil conditions, together with history and socioeconomic backgrounds in S. and C. Jiangsu are more suitable for the growth of LOGs. In addition, the distribution of LOGs may be also in connection with phyletic evolution to some extent, which are worthy of further study.
Tree-habitat types and growth status of LOGs

Most LOGs in Jiangsu Province grew well and were distributed in VF, RC and GC (Figs 3, 4a). Ginkgos grow well in a climate with four distinct seasons, in relatively low altitudes (≤ 1000 m), warm annual mean temperature (10–18 °C), moderate annual precipitation (600–1,000 mm) and high relative humidity (70–90%) (He et al. 1997; Tredici 2007; Liu et al. 2019b). Besides, ginkgos prefer fertile, moist and well-drained soil (He et al. 1995). The climate and soil conditions in Jiangsu Province are suitable for the growth of LOGs. As a result of the long cultivation period, ginkgos have been gradually endowed with religious, cultural and historical values (Jim 2004a; Lindenmayer et al. 2014). In Chinese traditional geomantic culture, ginkgos planted in the front of temples, houses and villages cannot be arbitrarily cut down, because these Fengshui woods are treated as protective barriers to keep buildings safe (Lü et al. 2009). These ancient trees connect villagers to previous generations and become part of the heritage in their family (Mahmoud et al. 2015). LOGs in the temple are also considered as “Buddha tree” or “sacred tree” (Ma 2003; Crane 2019; Huang et al. 2020). Therefore, people admire and actively protect these ancient trees.

However, approximately 15% of the LOGs in Jiangsu Province are still under threat due to mismanagement and urbanisation impacts (Figs 3, 4d) (Zapponi et al. 2017; Khapugin et al. 2020). For the sake of beauty and cleaning, building materials, such as cement, sometimes cover the soil around the stems of LOGs in PG and RS (Fig. 4d–6), which affects the root respiration of LOGs (Jim 2004b; Jim and Zhang 2013). Some citizens have deposited their electromotors, wastes and other miscellaneous items under these ancient trees which may degrade or destroy tree-habitats (Fig. 4d–4). The mean DBH value of LOGs in Jiangsu Province was 94.50 cm, the mean crown width was 11.39 m and the mean height was 17.01 m (Suppl. material 1), indicating that the growth of these ginkgos requires more open space. LOGs poorly performed in EC, RD and RS (Fig. 3b). The three tree-habitat types are characterised by high population mobility and rapid urbanisation. This situation causes ginkgos to be threatened with restricted space and insufficient light due to the shade from buildings (Fig. 4b, 4d–5, d–7). In addition, several natural events, such as lightning strikes, storms, insect infestations and epiphytic entwinement (Fig. 4c) also threaten the survival of LOGs (Yu and Gao 2004; Takács et al. 2020; Wang et al. 2020).

Suggestions for LOGs’ conservation

Based on the distribution features and tree-habitat quality of LOGs in Jiangsu Province, we offer three suggestions to conserve these ancient trees:

(1) Strengthening of LOGs’ management and protection

At present, there is a shortage of forestry skills in Jiangsu Province, especially professionals proficient in the protection and management of local ancient trees. The
Figure 4. Photographs of LOGs across different tree-habitat types in Jiangsu a panoramas of LOGs in good tree-habitat types in villages (VF) with (–1) open space and plenty of sunshine and (–2) no shade and good soil environment b panoramas of LOGs in bad tree-habitat types (–1) in the factory (EC) (–2) in the old town (RD) (–3) near the roadside (RS) c details of natural disasters experienced by LOGs in different tree-habitat types, including (–1) insect infestations, (–2) lightning strikes, and (–3) the effect of epiphytes d details of the anthropogenic interference experienced by LOGs in different tree-habitat types, including (–1) stuffing objects into the stem, (–2) incense burning and incense ash piling, (–3) a large number of red ropes wound around the branches, (–4) stacking sundries under the trees, (–5) the sheltered side of houses, (–6) cement-sealed ground and (–7) construction. The photographs were provided by Zhang G.F.
conservation of LOGs needs specialised knowledge. We suggest that provincial forestry authorities regularly provide professional guidance to the front-line management personnel of LOGs. These guidelines include pest control, epiphytes removal and pollarding (Zapponi et al. 2017). For those LOGs often disturbed by residents’ activities, large fences (at least as large as the crown width) should be installed around the trees (Mahmoud et al. 2015).
(2) Appropriate planning during urban and rural construction

The survival and protection of LOGs should be considered as an important factor and incorporated into urbanisation or rural reconstruction to ensure enough living space and good light conditions for these ancient trees. If a suitable ecological niche is maintained in the construction design and a large area of cement is replaced by lawn, the growth of LOGs can be guaranteed (Jim and Zhang 2013; Zhang et al. 2017; Lai et al. 2019). Sometimes, when problems, such as restricted space in old towns, are hard to resolve in urban reconstruction, the government can also consider transplanting these LOGs into urban parks or green space, where unenclosed overground space and underground soil can provide good growth conditions for tree stems and roots (Jim 2004b; Zhang et al. 2017; Lai et al. 2019). Moreover, for those LOGs still maintaining a good status, we suggest local forestry administration should recognise the dynamic development of LOGs and conserve their tree-habitats.

(3) Improvement of the relationship between religious culture and conservation measures

Worship of LOGs may sometimes unintentionally cause a major threat to their survival (Fig. 4d–1-3). For example, tourists often burn incense sticks around the stems of these ancient trees or even insert coins into the cracks of stems to pray for good fortune. Therefore, we should coordinate the relationship between LOGs’ protection and cultural custom. More specifically, it may be a good choice to build fences around the LOGs and set special places out of the fences for worship. Residents may also be mobilised to make conservation plans and work together for the protection of LOGs.

Conclusions

*Ginkgo biloba* is a Mesozoic relict species endemically distributed in China. We, for the first time, addressed the number, distribution and growth status of LOGs at the provincial level. The impacts of urbanisation and religious culture on both tree-habitat types and the growth of LOGs should be considered to conserve these ancient trees. Our findings can offer useful advice for the protection of LOGs in east China with a similar natural environment. Meanwhile, this study may provide a helpful reference for the regional conservation of other ancient trees. In addition, the effect of phyletic evolution on LOGs’ distribution deserves further study.

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Supplementary material 1

The large old ginkgos in Jiangsu Province, east China
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Data type: Occurences
Explanation note: The supplementary file includes two parts: the large old ginkgo (LOG) individuals and LOG groves in Jiangsu Province, east China. The first part contains the site, GPS, DBH, protection category, growth status and habitat of each LOG individual. The second part contains the site, GPS, mean DBH, number of ginkgos, growth status and habitat of each LOG grove. Dryad doi: 10.5061/dryad.gtht76hk6
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