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Leaf characters of *Ulmus elongata* in fragmented habitats: Implications for conservation

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ABSTRACT

Ulmus elongata is on the verge of extinction due to habitat fragmentation and habitat loss. Identifying the environmental factors affecting the leaf traits of *U. elongata* is important for understanding its endangerment mechanisms. Specific leaf area (SLA), leaf nitrogen content, and leaf carbon isotope discrimination ($\delta^{13}C$) were determined. Temperature and light were found to be the main environmental factors influencing SLA, indicating that *U. elongata* is heliophilous. The maximum and minimum $\delta^{13}C$ values of the plant species were −26.33‰ and −29.64‰, respectively (the mean was −28.09‰), suggesting that it is of the C_3 photosynthetic type. Compared with the altitude, annual sunshine duration, annual precipitation, and mean annual temperature accounted for 36% of the variance in $\delta^{13}C$, which is the main environmental factor affecting ^{13}C fractionation. The foliar $\delta^{13}C$ value of *U. elongata* was significantly more negative than that of *Ulmus pumila*, a widely distributed elm tree in northern China ($P < 0.05$), but the leaf nitrogen content of *U. elongata* was somewhat higher (33.30 mg g^{-1}) than that of the latter species (28.18 mg g^{-1}). These findings indicate that *U. elongata* has less photosynthetic stomatal limitation and higher carbon assimilation rates. Interestingly, across latitude gradients, the leaf $\delta^{13}C$ value of *U. elongata* became even more negative but the soil $\delta^{13}C$ value of the distribution sites became more positive, demonstrating low water use efficiency and abundance of C_4 plant species in warm and humid areas. SLA was observed to increase with increasing annual average temperature; the decrease in leaf $\delta^{13}C$ value indicates that water use efficiency lowers when water loss and transpiration strengthen in a high-temperature environment; these data revealed that the population of *U. elongata* may decline under global warming and drought stress. Several conservation strategies based on leaf characters and habitat traits were proposed.

1. Introduction

Ulmus elongata was first identified and classified as an Ulmaceae and *Ulmus* plant species by Fu [1] in Zhejiang, China. The discovery of *U. elongata* showed that *Ulmus* species extended from Asia, significantly prompting further research into North America and East Asia flora. *U. elongata*, sparse in China and inhabiting highly fragmented habitats, was declared as a state-protected plant [2]. Fast growing *U. elongata* has potential value as a source of medicinal agents and timber, with tall and straight stem.

Zou [3] and Jiang [4]found that seedlings of *U. elongata* did not regenerate under the canopy and the seeds only dispersed to short distances, both resulting in its current status. Gao et al. [5] reported that this species is considered endangered because of habitat fragmentation and habitat loss. The cutting breed of *U. elongata* is of the root callus type [6–7], and the seedling basal segment is the best material for asexual reproduction [8]. The number of sprouts is positively correlated with the diameter of the mother tree [9]; moreover, air temperature is the major environmental factor affecting 1-year seedling growth [10–12]. Despite these findings, we have only limited knowledge about the growth conditions and actual distribution of *U. elongata* in China, thereby inhibiting progress in conservation efforts and strategies.

Dispersal limitation and environmental conditions are crucial drivers of plant species distribution and establishment [13]. Identifying the main environmental factors affecting habitats as well as their survival adaptation preferences and elucidating the development patterns of *U. elongata* will valuably contribute to the current understanding of the endangerment mechanisms of this species and help inform prior conservation measures [14]. At the regional scale, plant functional traits are closely associated with climatic factors, but differences between traits do exist [15]. Plant leaves are considerably sensitive to environmental changes, making plant photosynthesis and water balances vital

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to plant growth. Some leaf traits reflect the relationship between plants and the environment, and affect plant growth and survival strategies. In light of these, the objective of this study was to ascertain (1) the environmental factors affecting *U. elongata* based on its leaf characteristics, (2) the trade-off between the environment and leaf traits of this species, and (3) implications for its conservation.

2. Sites description and methods

2.1. Sites description

According to our field experiments conducted over the past two years, *U. elongata* was distributed in Shexian, Anhui (AHSX); Lin'an, Zhejiang (ZJLA); Kaihua, Zhejiang (ZJKH); Songyang, Zhejiang (ZJSY); Wuning, Jiangxi (JXWN); Suichang, Zhejiang (ZJSC); and Nanping, Fujian (FJNP) (Fig. 1). The soils were black or yellow, the average annual temperature ranged from 16.2 to 19.5 °C, the annual rainfall measured between 1488 and 1856 mm, and the annual sunshine duration (ASD) lasted >1700 h, except in ZJKH (Table 1).

2.2. Methods

All investigations were processed during the June–October growth periods of 2009 and 2010; a 10 m × 10 m plot was each investigated in ZJSY and JXWN, whereas a 20 m × 20 m plot was used in all the other sites. The trees, shrubs, and herbs in each plot were recorded. Elevation (ELE), latitude, and longitude were measured using a GPS detector. The slope, aspect (ASP), tree layer coverage (TLC), and bare rock ratio (BRR) were also determined. Human interferences were designated as extremely minor, minor, moderate, or severe according to actual destruction conditions.

2.3. Specific leaf area

More than three trees were sampled in each area, and 8–15 leaves exposed to sunlight were picked from each tree. Sun leaves at different positions were taken if there were less than three mother trees. After the surfaces of the leaves had been cleaned, they were fixed in an oven at 105 °C and then dried to constant weight at 80 °C. The leaves were scanned using a CanoScan 4400F (Canon, Japan) and weighted using 1/10,000 electronic balance. The specific leaf area was designated as follows: SLA ($cm^2\ g^{-1}$) = leaf area / leaf mass.

2.4. Soil and foliar carbon and nitrogen content and carbon isotope discrimination ($\delta^{13}C$)

The surface soils were sampled around each mother tree, and soil pH was measured using a Sartorius 300 pH detector; the soil/water ratio was 1:5. Data were expressed as the mean of three replicates. The leaves were picked from the canopy as described in Section 2.3. The leave and soil materials were first crushed using a mortar and then sieved through 200 mesh. The carbon (C) and nitrogen (N) contents (%) were analyzed using a VARIO EL3 precision elemental analyzer (Elementar, Germany), and the C/N ratio of each plant's shoots was calculated in Excel 2007 (Microsoft, USA). Approximately 3- to 5-mg samples were analyzed on a Delta XP isotope ratio mass spectrometer (Finnigan MAT253) following pyrolysis in a high-temperature furnace (Thermoquest TC/EA, Finnigan MAT). The carbon isotope

Fig. 1. Geographic sites of *U. elongata* and *U. pumila* evaluated in this study. The yellow marker denotes *U. elongata*, whereas the green one denotes *U. pumila*.