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Latitudinal patterns of leaf N, P stoichiometry and nutrient resorption of *Metasequoia glyptostroboides* along the eastern coastline of China

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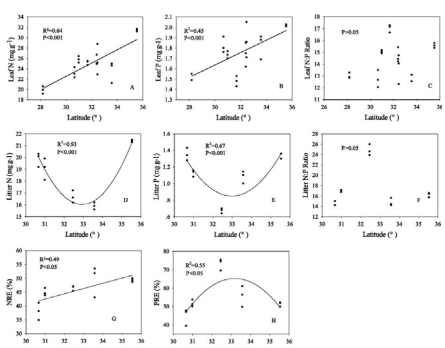
HIGHLIGHTS

- Latitudinal patterns of stoichiometry were found with similar Alt. and Long.
- Leaf N, P and NRE increased driven by heat, water and light resource.
- PER first increased and then decreased, impacted by soil available P.
- Leaf and litter N:P showed stable and no latitudinal pattern.

GRAPHICAL ABSTRACT



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ABSTRACT

Latitudinal patterns of leaf stoichiometry and nutrient resorption were not consistent among published studies, likely due to confounding effects from taxonomy (e.g., plant distribution and community composition), and environment, which is also influenced by altitude and longitude. Thus, the latitudinal patterns and environmental mechanism could be best revealed by testing a given species along a latitude gradient with similar altitude and longitude. We determined nitrogen (N) and phosphorus (P) concentrations of green (leaf) and senesced leaves (litter) from eight *Metasequoia glyptostroboides* forests along the eastern coastline of China, with similar altitude and longitude. Leaf N, P concentrations increased along latitude, mainly driven by mean annual temperature (MAT), mean annual precipitation (MAP), annual evaporation (AE), aridity index (AI), and annual total solar radiation (ATSR); While leaf N:P ratio was stable with no latitudinal pattern. Nitrogen resorption efficiency (NRE) increased along latitude, and was also mainly influenced by MAT, MAP, AE, and AI. Phosphorus resorption efficiency (PRE) first increased and then decreased with latitude, which was impacted by soil available P. These results indicated that only climate (such as heat, water, and light) controlled the shift in leaf stoichiometry and NRE, while soil nutrient was likely responsible for the shift in PRE along eastern China. Our findings also suggested that leaf N, P stoichiometry and NRE displayed similar latitudinal patterns at regional scale when studied for a given species (this study) or multi-species (previous studies).

1. Introduction

Leaf stoichiometry is a key measurement in the study of variations of plant nutrients (Wang et al., 2015), and nutrient resorption is an

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essential mechanism of nutrient conservation in plants (Du et al., 2016). Both leaf stoichiometry and nutrient resorption may yield new insights into plant nutrient limitations, nutrient cycling, and plant responses to climate change (Elser et al., 2010; Esser et al., 2011; Austin and Vitousek, 2012; Sistla and Schimel, 2012; Cornwell and Cornelissen, 2013). The latitudinal patterns of leaf stoichiometry and nutrient resorption efficiency (NuRE) have been studied extensively (Elser et al., 2000; He et al., 2006; Wu et al., 2012; Zhou et al., 2014; Li et al., 2015). Leaf nitrogen (N) and phosphorus (P) concentrations increase (Reich and Oleksyn, 2004; Han et al., 2005; Townsend et al., 2007), while leaf N:P ratio decreases (Reich and Oleksyn, 2004; McGroddy et al., 2004; He et al., 2008) with increasing latitude. In terms of litter stoichiometry and NuRE, litter N concentration and leaf P resorption efficiency (PRE) decrease, while litter P concentrations and leaf N resorption efficiency (NRE) increase with increasing latitude (Yuan and Chen, 2009a, 2009b; Tang et al., 2013).

The latitudinal patterns of leaf stoichiometry and NuRE for a single species have become a focus in recent years (Ågren and Weih, 2012; Rivas-Ubach et al., 2012; Zhou et al., 2014; Sun et al., 2015, 2016; Hu et al., 2017). To our knowledge, these patterns were different from the results for multi-species studies; for example, leaf N or P concentrations showed no significant relationship with latitude (Zhou et al., 2014), and both NRE and PRE increased for a given species (Oleksyn et al., 2003; Chen et al., 2014; Sun et al., 2016). These inconsistent results may be due to the differences of plant distribution and community composition associated with multi-species studies (Du et al., 2016), which can directly or indirectly affect leaf stoichiometry and nutrient resorption. Therefore, studying a single species should better reveal the latitudinal patterns of leaf stoichiometry and nutrient resorption.

Meanwhile, the results from studies on single species were not in agreement and even contradictory. For instance, although leaf N and P concentrations had no latitudinal trends as mentioned, they were also found to increase with increasing latitude (Sun et al., 2015; Hu et al., 2017), and PRE was shown to increase in some studies (Oleksyn et al., 2003; Sun et al., 2015). These inconsistent or contradictory results can be attributed to the complexities of latitudinal environments; For example, temperature and moisture, which affect plant stoichiometry, are significantly affected by other geographical factors (e.g., altitude, longitude) in addition to latitude.

Metasequoia glyptostroboides Hu & W.C. Cheng is the most important tree species in coastal shelterbelts in eastern China (Wu et al., 2013), and is widely distributed from the northern warm temperate region to the southern subtropical region with similar altitude and longitude. This ideal geographic distribution provides a natural experiment to examine the latitudinal trends of leaf N, P stoichiometry and nutrient resorption. In this study, we determined the leaf and litter N and P concentrations for *M. glyptostroboides* of similar ages. The objective of our study was to test 1) the latitudinal patterns of leaf N, P stoichiometry and nutrient resorption for *M. glyptostroboides* without regard to longitude and altitude, and 2) the environmental mechanism on leaf N, P stoichiometry and nutrient resorption of *M. glyptostroboides*.

2. Materials and methods

2.1. Study area

M. glyptostroboides is a rare deciduous conifer of the family *Cupressaceae*. It is native to western Hubei, northern Hunan and eastern Sichuan provinces in central China (Chu and Cooper, 1950; Fu and Jin, 1992). Following its discovery as a living species, the species has been planted in numerous locations throughout the world (Williams, 2005). It is also the main species of shelterbelts in China's coasts. Since 1970s, plantations have been chronologically established along eastern coastline of China (Wu et al., 2013).

According to the distribution of *M. glyptostroboides* forests in the coastal areas, eight sites with similar altitude and longitude were selected (Fig. 1). The latitude (LAT), longitude (LON) and altitude (ALT) of each site were recorded with a global positioning system (GPS MAP 621sc) and are given in Table 1. Mean annual temperature (MAT), mean annual precipitation (MAP), annual evaporation (AE), aridity index (AI), and annual total solar radiation (ATSR) for the eight sites were derived from the WorldClim 1.4 database (http://www.worldclim.org/), a global dataset with spatial resolution of *c.* 1 km^2.

2.2. Sampling of leaf, litter and soil

M. glyptostroboides pure stands were selected for sampling based on the following criteria: stands were at least 20 years old, with no significant disturbance and trees grew well. In each selected stand, three plots (20 m × 20 m) were established for leaf and litter sampling. In September 2015, three average trees were selected within each plot (from north to south) for leaf sampling. From each sample tree, 3–5 sunlit branches were identified and leaves from the middle branches were harvested. All the leaf samples were quickly placed in bubble chambers with ice blocks before they were transported to the laboratory.

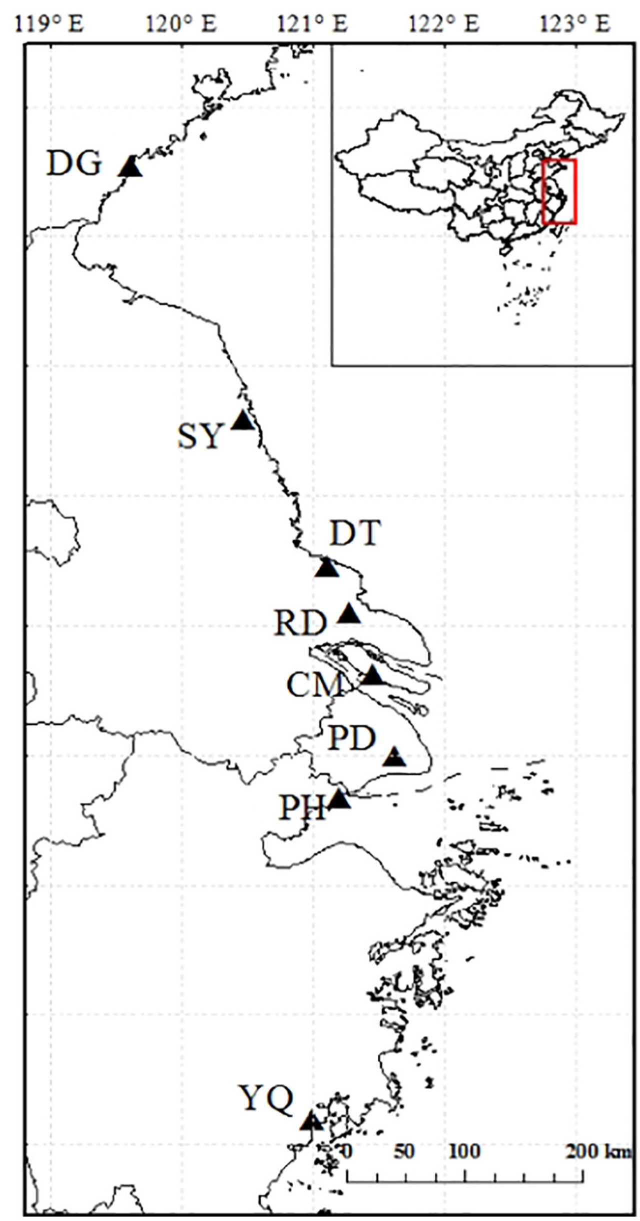

Fig. 1. Distribution map of *Metasequoia glyptostroboides* stands sampled along the coastal areas of eastern China. The identification letters of locations are found in Table 1.