



Contrasting water sources of evergreen and deciduous tree species in rocky mountain area of Beijing, China



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ABSTRACT

Trees growing in the Beijing mountain area are often located on rocky outcrops. As water sources for these trees are poorly understood, we investigated seasonal water sources of four typical tree species (*Platycladus orientalis*, *Pinus tabulaeformis*, *Robinia pseudoacacia* and *Quercus variabilis*) using stable hydrogen and oxygen isotope methods in this area. Results indicate that *P. orientalis* predominantly utilized water from natural springs (57.8%) during the dry season and uptake water from shallow layer (0–20 cm, 78.4%) during the wet season. *P. tabulaeformis* predominantly utilized shallow (46.8% and 37.7%, respectively) and deep (60–100 cm, 24.9% and 27.6%, respectively) soil water in the dry and wet seasons. *R. pseudoacacia* mainly absorbed shallow soil layers water (54.3%) during the dry season and switched its water source to all of the soil layers (19.2–30.9%) during the wet season. *Q. variabilis* predominantly extracted water from the shallow (29.8%) and middle (20–60 cm, 38.6%) soil layers during the dry season; and it primarily relied on middle layer soil water (25.9%) and natural springs (40.5%) in the wet season. These four tree species showed a strong adaptation to drought periods and our findings provide valuable information which can be used when selecting tree species and planning long-term ecological management of afforestation around the Beijing mountain area.

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1. Introduction

A shortage of water, one of the world's most important eco-environmental issues, has led to widespread concern in the ecological community (Liu et al., 2012; Bai et al., 2008). A shortage of water can cause considerable damage to environments in arid and semi-arid fragile ecosystems where, with climate prone to drought and evapotranspiration exceeding precipitation, water is the key influential limiting factor of vegetation coverage, biomass and diversity (Knapp et al., 2001; Boyer, 1982). Therefore, it is quite necessary to know the water use strategies of coexisting species when water inputs are limited in arid and semi-arid regions. In these regions, tree species may extract water from diverse soil depths or use natural springs (Ehleringer and Dawson, 1992; Dai et al., 2014; Nippert and Knapp, 2007). The sources of water in tree can be identified by contrasting the δD and $\delta^{18}O$ values of water extracted from its branches with all potential water sources (Phillips and Gregg, 2003; Dawson, 1996). Apart from in halophytes, isotopic fractionation during water absorption and transportation between roots and leaves before transpiration does not occur (Walker et al., 2001). This relatively new research method has been widely applied in ecology (Gazis and Feng, 2004; Asbjornsen et al., 2007). Previous investigations have shown that by using stable isotope techniques and

analyzing the δD and $\delta^{18}O$ values of plant branch water, it is possible to clarify water sources in arid and semi-arid forest ecosystems (Kambatuku et al., 2013; Moreno-Gutiérrez et al., 2015; Leffler and Caldwell, 2005). For example, Li et al. (2006) showed that water sources of the deciduous tree *Larix sibirica* Ledeb had seasonal variation characteristics during the growing season in northern Mongolia. During seasonally dry periods, as well as in arid and semi-arid zones, many trees uptake water from deep soil layers using deep root systems when shallow soil layers is limited (Romero-Saltos et al., 2005; West et al., 2008; Quesada et al., 2008). Similarly, deciduous and evergreen trees have adapted soil water availability by modifying root density during the dry season (Schwinning, 2008). Ellsworth (2012) also found that root density in deciduous and evergreen species increase from the dry to wet season, and that the increase in root density is greater in evergreen species than in deciduous species. Nie et al. (2012) reported that the deciduous tree *Radermachera sinica* absorbed water from deep soil layers during the late droughts and switched to shallow soil layer (0–30 cm) during the early droughts, their results also showed that *Alchornea trewioides* was always dependent on recent rainwater or shallow soil water. As seasonally dry regions have insufficient precipitation and uneven annual water distributions which can result in a deficiency of soil water to maintain tree growth (Nie et al., 2011; Andrade et al., 2005), the ability to change main water sources from shallow to deep soil layers (or from deep to shallow soil layers) is highly important for tree growth.

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Currently, although the majority of investigations have been undertaken in arid or semi-arid regions, the water sources of typical tree species during the growing season in the Beijing mountain area are unknown. This area, being dominated by a semi-humid and semi-arid continental monsoon climate, is characterized by thin soils and high vegetation coverage. This area is an important ecological barrier in the North China Plain and Beijing city. However, it is unclear as to the water use pattern for typical tree species during the dry and wet seasons.

To fill these gaps, we investigate water sources of trees in this area. *P. orientalis*, *P. tabuliformis*, *R. pseudoacacia* and *Q. variabilis* were selected as typical dominant tree species. Deuterium (δD) and oxygen ($\delta^{18}O$) isotope techniques were used to identify the source of water in tree branches; soil water and natural springs were analyzed to identify water sources during the growing season.

2. Materials and methods

2.1. Study area and tree species

The study site lies in at the Research Station of Forest Ecological System (RSFES) in the capital circle (Fig. 1b), Jiufeng National Forest Park, northwest Beijing, north China (116°05'E, N40°03'N) (Fig. 1a). RSFES, founded in 1986, aims to study forest ecological hydrology within the area. Since the 1950s, the local Forestry Bureau has planted trees to restore vegetation; currently a large area of the National Park is dominated by trees and shrubs. This area belongs to north China warm temperate semi-arid continental monsoon climate. The air area has an average temperature of 11.6 °C, with mean monthly air temperatures varying between −5 °C (November) and 30 °C (July). The growing

season typically lasts for about 150 days, April to the end of October. Annual average precipitation is 650 mm with 70–80% occurring in wet season (between July and September). Mean annual evapotranspiration is approximately 1100 mm. The National Park has a forest cover of approximately 85%.

P. orientalis, an evergreen coniferous tree, is widely distributed across the China, except for the Qinghai Province and the Xinjiang Uygur Autonomous Region. This tree species is a typical species in the Beijing mountain area, and it has been chosen as the city tree of Beijing City. It has a developed root structure in shallow soil with a simple tap-root system (Lin et al., 1996). It is highly tolerant of drought conditions and it can accommodate changes soil moisture conditions (Richards and Burningham, 2011). *R. pseudoacacia* is a deciduous broad-leaved tree which originated in North America and has been widely introduced into other continents, such as in Asia and Europe. This tree species has been incorporated into many acres of reforestation in the North China plain along the Yellow River, as well as in other areas for the green and Ling star planting. *R. pseudoacacia* has a shallow root system which is sensitive to water, and it has a strong adaptability for fine sandy soil (Danjon et al., 2013). In our study, *P. orientalis* stands grew together and mixed with *R. pseudoacacia* stands. The average diameter at breast height (DBH) of *R. pseudoacacia* was 8.8 cm, this being lower than the DBH of *P. orientalis*. The average height of *P. orientalis* and *R. pseudoacacia* were similar (Table 1).

P. tabuliformis, an evergreen coniferous tree, is mainly distributed in the western and northern areas of China. This species has a developed root system which not only makes it highly adaptable and fast-growing, it is also drought resistant and able to grow in barren soils. This tree is the main afforestation species in the Beijing mountain region. *Q. variabilis*, a deciduous broad-leaved tree, is widely distributed across

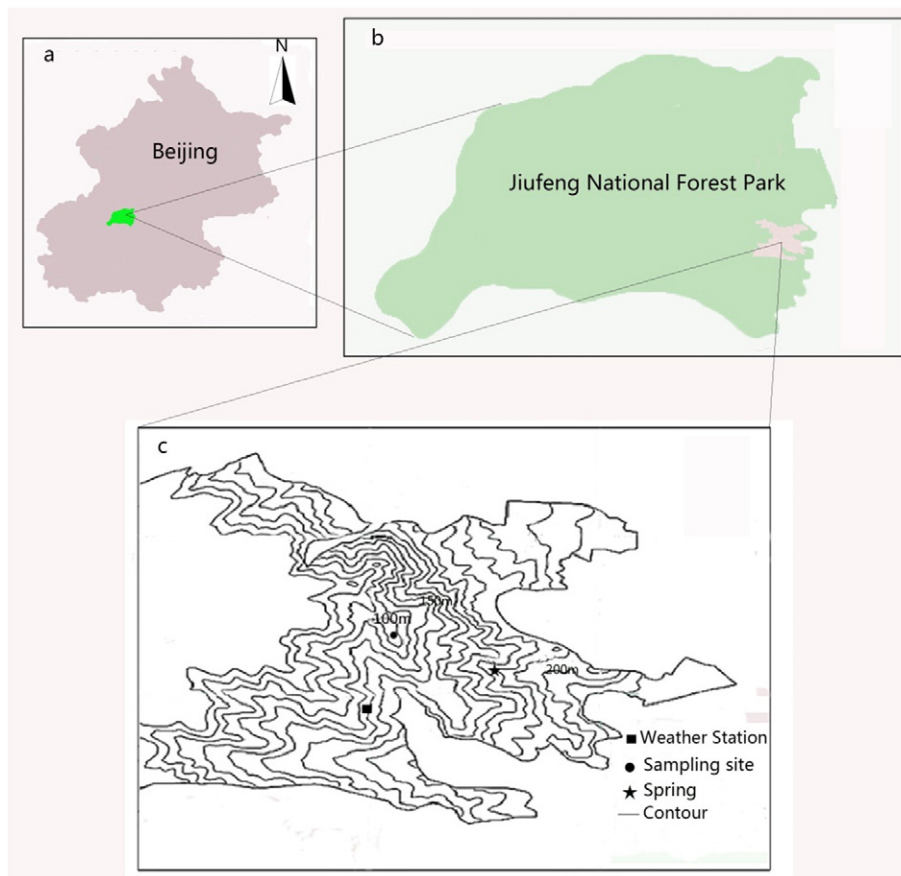


Fig. 1. Map of the study region and the field area. (a) Location map of Jiufeng National Forest Park within Beijing, China. (b) Location map of Jiufeng National Forest Park. (c) The sampling site within location the RSFES.

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