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Water use strategies of *Populus euphratica* seedlings under groundwater fluctuation in the Tarim River Basin of Central Asia

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ABSTRACT

Riparian vegetation in arid regions is subject to frequent water environmental fluctuations and plays an important role in maintaining the riparian ecosystem. In recent decades, *Populus euphratica (P. euphratica)* has been threatened by decreasing groundwater levels, and large areas of *P. euphratica* seedlings are withered. To better understand the adaptive mechanism underlying hydrological process alterations, we designed an experiment to identify the water sources of *P. euphratica* seedlings using $\delta^{18}O$ values (plant stem xylem, soil water and groundwater) under different groundwater scenarios by simulating the wild habitats conditions in the Tarim River bank of Central Asia. Seedlings were grown in lysimeters (2.0 m tall × 0.4 m inner diameter) under varying hydrological conditions. *P. euphratica* seedlings generally took up water from the shallow soil layer (0–80 cm). Under the *T. ramosissima* disturbance, the water source depths of the *P. euphratica* seedlings moved down as the groundwater depth increased. With increasing groundwater depth, the proportions of groundwater used by *P. euphratica* seedling monocultures (only *P. euphratica* seedlings) and *P. euphratica* seedling mixtures (*P. euphratica* and *T. ramosissima* seedlings) were reduced. Under shallow groundwater treatment (W_1: 25 cm), the plant height growth of the *P. euphratica* seedlings slowed, and their biomass accumulation decreased. The aboveground and total biomasses of the non-coexistence seedlings under W_2 (75 cm) treatment were maximized, while the maximum value for coexistence seedlings occurred under W_3 (125 cm) treatment. Thus, we suggest that shallow groundwater depth is not beneficial to *P. euphratica seedling* growth, and appropriately decreasing the groundwater depth may promote their growth. Such information will be valuable to provide the configuration of water resources for a typical river basin in an arid region of Central Asia based on the ecological water requirements of desert riparian vegetation.

1. Introduction

Populus euphratica Oliv (*P. euphratica*), an important part of riparian ecosystems in arid regions of Central Asia, plays significant roles in maintaining river basin ecosystem stability, sand resistance and saline-alkali soil improvements (i.e., the forest canopy can slow down the salinization process, and large leaves and branches can increase soil fertility) (Chen et al., 2008). *P. euphratica* is the sole species responsible for formulating the forest community in arid desert regions in China (Wang et al., 1995). Commonly, seedlings appear on bare, moist and newly deposited sediment near the active river channel, and the growth situations are significantly limited by the groundwater and soil salinity (Guilloy et al., 2011; Imada et al., 2008; Li et al., 2013; Forget, 2007). The seedling growth status is key to determining the succession process of the riparian plant community (Li et al., 2012; Sher and Marshall, 2003), and succession from *P. euphratica* seedlings to the established mature population is influenced by hydrological fluctuations, including the interplay between river dynamics and groundwater changes (Eusemann et al., 2013; Schnittler and Eusemann, 2010; Thevs et al., 2008; Wiehle et al., 2009).

To date, numerous studies have been carried out to evaluate the dynamics of *P. euphratica* seedlings in Asia, Europe and North Africa, mainly focusing on ecological characteristics (González et al., 2009; Gries et al., 2003; Imada et al., 2008; Rüger et al., 2005), stress resistance (Li et al., 2012; Li et al., 2013; Wang et al., 2015) and water utilization strategies (Chen et al., 2011; Liu et al., 2015; Zhou et al., 2015). There is evidence that *P. euphratica* is relatively flood-tolerant due to a combination of morphological, physiological, and biochemical

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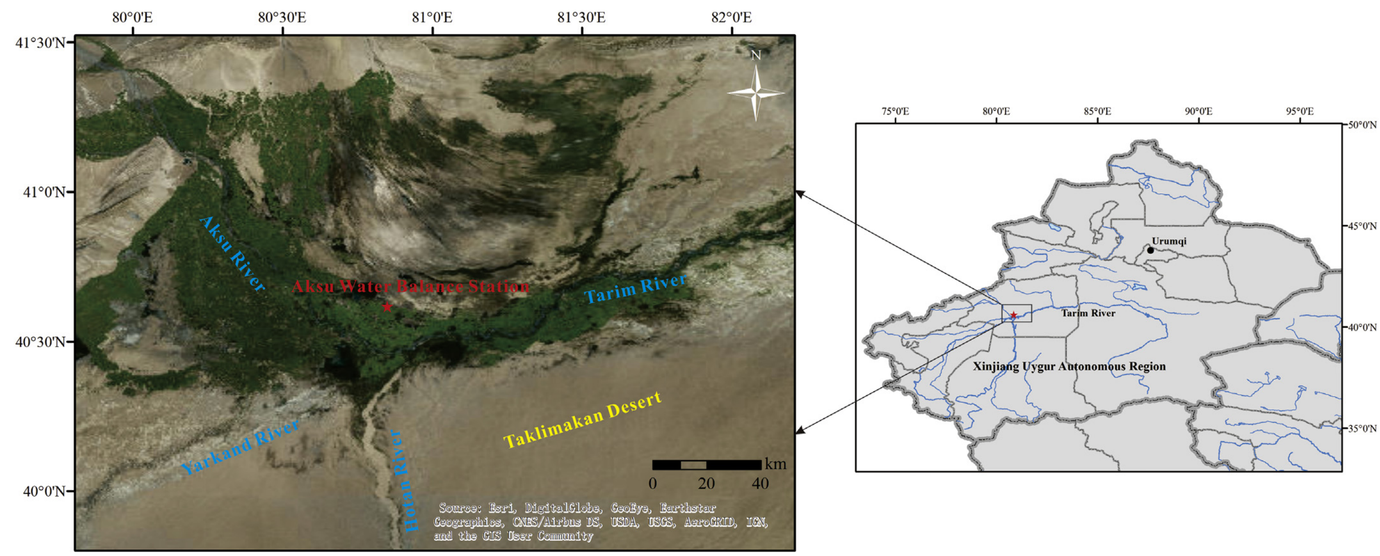

Fig. 1. Location of the study site.

adjustments (Yu et al., 2015), and *P. euphratica* seedlings subjected to drought suffer from considerable water stress (Li et al., 2012). In addition, no seedlings survive when the water table declines in coarse substrates, although survival is high (85%) under saturated conditions (González et al., 2009), and the sediment type may play a significant role in seedling root traits (Wang et al., 2015). In arid regions, groundwater depth substantially influences the fine-root growth and mortality of *Populus* species (Gries et al., 2003; Guilloy et al., 2011; Imada et al., 2008; Rüger et al., 2005; Wang et al., 2015). For its water utilization strategy, *P. euphratica* mainly uses soil water and groundwater, and its water uptake ability is influenced by the groundwater table and interspecific competition (Liu et al., 2015; Zhou et al., 2015).

Common approaches to quantifying different water sources are conducted by excavation of a plant's root system (Dahlman and Kucera, 1965; Feng et al., 2008; Jackson et al., 1996; Wang et al., 2010) and stable isotope analysis (Brunel et al., 1997; Darling et al., 2003; Ewe et al., 2007; Mensforth et al., 1994; Schwendenmann et al., 2014; Swaffer et al., 2014). Excavation of roots to determine their spatial distribution is destructive, time consuming and impractical in many ecosystems (Duan et al., 2008; Meinzer et al., 2001). Water stable isotopes can provide useful information on resource complementary among individuals of a population (Cheng et al., 2006; Liu et al., 2015b), especially in studies on plant species diversity effects or neighbourhood relationships (Meißner et al., 2014; Schwendenmann et al., 2010). In practicality, analysis of $\delta^{18}O$ values in different soil layers is an effective way to trace water sources for plant uptake due to the absence of isotopic fractionation during terrestrial plant water uptake (Wershaw et al., 1966).

The Tarim River is approximately 1321 km long. It is an inland river located in the Tarim Basin, the most arid basin in China. Riparian forests are dominated by *Populus euphratica* Oliv and *Tamarix ramosissim* Ledeb (Zhang et al., 2005b), and some competition exists between these species for similar niche habitats (Li et al., 2012; Merritt and Poff, 2010; Sher and Marshall, 2003). Regarding the Tarim River Basin, recent studies have shown that *P. euphratica* is highly dependent on the groundwater availability, evidenced by plant-water relationships and hydraulic conductance (Fu et al., 2006; Zhou et al., 2013). Most studies on *P. euphratica* water-use strategies focus on mainly the Heihe River Basin. Young forests mainly use shallow soil water (Cheng et al., 2014; Liu et al., 2015), and mature and over-mature forests primarily derive the groundwater (Liu et al., 2015; Zhao et al., 2008). Substantial progress on improving the water-use efficiency and water sources of riparian vegetation has been achieved. However, little has been done to quantitatively assess the water competition and dynamics of *P. euphratica* seedlings under different water gradients in the Tarim River Basin. Therefore, this study was designed to identify the water source of *P. euphratica* seedlings using the $\delta^{18}O$ values of plant stem xylem, soil water and groundwater under different groundwater scenarios based on simulating the wild establishment conditions in the Tarim River bank. Thus, we expected to reveal the mechanisms underlying the ecological and hydrological processes of desert riparian plants in arid areas.

2. Materials and methods

2.1. Site description

With an area of 1.0×10^6 km^2, the Tarim River Basin covers the entire southern part of Xinjiang in western China. The main catchment covers an area of 17,600 km^2, behind the confluence of the Hetian, Yarkand, and Akesu rivers, fed by water from glaciers and snowmelts as well as rainfall in the mountains. The region is extremely arid with an annual precipitation of $<$ 50 mm, but potential evaporation in the area exceeds 2000 mm per year. The annual cumulative temperature $\geq$ 10 °C varies between 4039 and 4274 °C (Chen et al., 2006). Desert riparian forests composed mainly of *P. euphratica* are grown on both sides of the Tarim River (Ling et al., 2015). Shrub vegetations mainly include *Halostachys caspica*, *Tamarix and Haloxylon ammodendron*, *Nitraria sibirica*, and the main herbs are *Phragmites australis*, *Alhagi sparsifolia*, *Glyzyrrhiza inflate* and *Karelinia caspica* (Ling et al., 2014).

The experiments were conducted at the Aksu Water Balance Station (40°37′ N, 80°51′ E, 1028 m above sea level), located 30 km north of the Tarim River (Fig. 1). Over the past 30 years (from 1986-2015), the mean annual air temperature is approximately 11.6 °C, the mean annual precipitation is approximately 63 mm, and the mean annual potential evaporation is approximately 2500 mm (Yu et al., 2018). The major soil type is shrubby meadow soil, and the soil texture is silt loam around the station (Han et al., 2016; Yan et al., 2009). Strong winds blow frequently in the region. During the experiment, approximately 80 mm of precipitation fell from July to September, and the average annual temperature was 23.2 °C. The maximum temperature of 37.8 °C was observed in July, and the minimum temperature of 5.6 °C was observed in September.