

SPECIAL ISSUE PAPER

Growth and water relations of riparian poplar forests under pressure in Central Asia's Tarim River Basin

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Abstract

The riparian forests in the Tarim Basin (NW China) are mainly composed of poplar species (*Populus euphratica*, *Populus pruinosa*). In the hyper-arid climate of this region, the trees are phreatophytes, which rely on access to groundwater. Essential ecosystem services (ESS) of these forests comprise provisioning, regulating, and cultural services. The ESS of the forests are threatened by overuse and a continuous decrease in the groundwater level due to excessive use of water for agriculture, which resulted in a severe reduction of the poplar forest area during the past decades.

Studies revealed that the wood of the forests could be sustainably used through a moderate harvesting intensity. Rejuvenation of the forests from seeds is only possible after sediment deposition and wetting of the soil surface upon flooding and at relatively short distances to the groundwater. At sites with larger groundwater distances, trees can only regenerate vegetatively through root suckers emerging from underground root spacers. With increasing distance from the water table, the stands become older and sparser and, ultimately, are doomed to die off. The research results can contribute to develop suitable management schemes for the conservation and protection of Central Asia's riparian forests. The lower reaches of the Tarim River have been subjected to a water release programme for the past 20 years. We recommend focusing the diversion of such additional ("ecological") water to stands with a short distance to the groundwater to keep these forests fully functional and to maintain their ability to regenerate from seeds.

KEYWORDS

clonal growth, ecosystem service, phreatophyte, pollarding, poplar, review, *tugai* forest, water table

1 | INTRODUCTION

The riparian (floodplain) forests of Central Asia, from the Caspian Sea in the West to the Tarim and the Dzungarian basins in the East, are called *tugai*. These forests grow along the river shores on floodplains at slightly elevated sites that are inundated for only a short period of the year (Walter & Breckle, 1994). In NW China (province of Xinjiang),

they mainly occur along the Tarim River system, which, with a length of >2000 km (including tributaries), belongs to the longest river systems of Central Asia. The Tarim River originates from the confluence of four smaller rivers (Aksu, Yarkant, Kashgar, and Hotan) in the Tarim Basin at the northern fringe of the Taklamakan Desert and flows to the East, then to the South to empty into the endorheic Taimema Lake. At the southern border of the Tarim Basin, several smaller rivers

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originate from the Kunlun Mountain range and end up farther north in the desert.

Forests along those river shores grow in a climate that, according to the UNESCO-based definition of the ratio of average annual precipitation (P) to evapotranspiration (ET; Whitford, 2002), is hyper-arid ($P/ET < 0.03 \text{ mm mm}^{-1}$). Under these conditions and at an annual precipitation that, in some regions, is lower than 50 mm, the perennial plant species generally are phreatophytes in the sense of Meinzer (1923), which—for survival and growth—rely on temporary or even permanent access to groundwater for the uptake of water and mineral nutrients (Thomas, 2014). Euphrates poplar (*Populus euphratica* Oliv.; syn. *P. diversifolia* Schrenk) and pruinose poplar (*P. pruinosa* Schrenk) are the dominating tree species (Walter & Box, 1983), whereas the widely distributed co-occurring *Tamarix ramosissima* grows as a shrub. Generally, the phytodiversity of the *tugai* forest is low (Thevs, Zerbe, Peper, & Succow, 2008).

The *tugai* forests provide essential ecosystem services (ESS) for the local and regional population in NW China and neighbouring regions. Traditionally, wood and leaves of the trees are used for fuel, timber, and fodder (Säumel, Ziche, Yu, Kowarik, & Overdieck, 2011; Thomas et al., 2000; Wang, Chen, & Li, 1996). Understorey plants are collected for construction and handicraft purposes and for nutritional and medicinal use. Poplar stands also constitute an important shelter against sand drift and soil erosion (Betz, Halik, Kuba, Tayierjiang, & Cyffka, 2015; Mamat, Halik, Aishan, & Aini, 2019; Xia et al., 1993). In addition, the forests are a refuge for threatened animal species (Hai, Wai, Hoppe, & Thevs, 2006; Qiao, Yang, & Gao, 2006) and are a relevant resting place for migratory birds (World Wildlife Fund, 2014).

In Xinjiang and other Central Asian regions, the rapidly growing human population and the pressure to produce cash crops such as cotton that are competitive on the global market even increase the pressure on the (near-)natural ecosystems. Thus, in many parts of Central Asia, ESS of the riparian forests are threatened by overuse, by a continuous decrease in the groundwater level, and by salinization. In the Tarim Basin, changes in the land use have resulted in a severe reduction of the poplar forest area during the past decades (Geist, 2005; Wang et al., 1996). At the northern rim of the Tarim Basin, excessive use of water for agricultural areas has led to a drastic drop of the groundwater level and to the decline of poplar forests particularly in the lower reaches of the Tarim River (Feng et al., 2005). Natural impacts such as the outbreak of insect herbivores in the mostly monospecific tree stands (cf. Gärtner, Förster, & Kleinschmit, 2016; Zheng et al., 2014) and sand storms (Hai et al., 2006; Xia et al., 1993), which might be aggravated through anthropogenic action, can exacerbate the pressure on the forests. The distance to the groundwater also affects phytodiversity (Zhang, Chen, & Pan, 2005). After degradation, possible recovery or new establishment of the forests seems to be dependent on controlled flooding (Tao, Gemmer, Song, & Jiang, 2008; Westermann, Zerbe, & Eckstein, 2008) or on the presence of a shallow groundwater table (Khamzina, Lamers, & Vlek, 2008). Therefore, a water release programme was launched in 2000 to supply the lower reaches of the Tarim River with additional (“ecological”) water.

This article aims at reviewing recent studies on biomass production and water relations as crucial compounds of the *tugai* forests' functions and the responses of these functions to the principal pressures, with a focus on the past two decades of research in the Tarim River Basin. On that basis, we formulate management recommendations for the conservation of the forests against the background of climate change and dwindling resources. These recommendations may also be relevant for poplar-dominated riparian forests suffering from decreases in water supply in other (semi-)arid regions of Central Asia, for example, along the Amu Darya of Uzbekistan (Schlüter et al., 2013; Treshkin, 2001), and along the Syr Darya river system and in the Ili-Balkhash basin of Kazakhstan against the background of the prospected climate change (Nurtazin et al., 2019; Sorg et al., 2014).

2 | LIFE HISTORY AND REJUVENATION OF RIPARIAN POPLAR FORESTS

The *tugai* forests of the Tarim Basin cover an area of ~352,000 ha and, thus, make up for some 54% of the world's *Populus euphratica* forests (Hai et al., 2006). At the river shores, *P. euphratica* can germinate from seeds only after intense flooding when the soil is sufficiently moist (Cao et al., 2012; Xu, Ye, & Li, 2009) and sufficient open space without competing vegetation is available (for comparable results on Salicacean species of the Northern Hemisphere, cf. González et al., 2018 and Karrenberg, Edwards, & Kollmann, 2002). A continuously wet substrate also provides the most favourable condition for seed germination and seedling survival of other poplar species in temperate regions of Europe and North America (Guilloy-Froget, Muller, Barsoum, & Hughes, 2002, and literature cited therein). Under such conditions, the emerging roots of *P. euphratica* can grow rapidly down to the capillary fringe of the water table if the distance to the groundwater is not larger than 2 m (Thevs et al., 2008). Throughout the temperate zone of the Northern Hemisphere, *Populus* and *Salix* species of the Salicacean family are known to be particularly successful in rapidly colonising sediments on river shores after flooding (Karrenberg et al., 2002). During the life history of the trees and stands, the distance of the trees' aboveground parts to the groundwater often increases (Figure 1) as a result of lowering of the groundwater level (upon changes in the course of the river, for example, Li, Yu, Brierley, Wang, & Jia, 2017; Thevs et al., 2008); of anthropogenic withdrawal of water from the river for extensive irrigation of agricultural land (Feng et al., 2005; Thevs, Peng, Rozi, Zerbe, & Abdusalih, 2015; Yimit, He, Halik, & Giese, 2006); or by wind-driven sand accumulation (Wang & Jia, 2013; Xia et al., 1993). To a certain extent, *P. euphratica* trees are capable of keeping pace with sand encroachment through height increment of the stem (cf. Gries et al., 2003). At larger distances to the groundwater, where seeds cannot germinate due to the absence of inundation, regeneration is only possible vegetatively through “root suckers.” These are shoots emerging from horizontally running underground root sections (spacers) connected to the “parent” plant. Such shoots are initiated in soil depths down to ~0.6 m and reach distances of up to 40 m from the “parent”

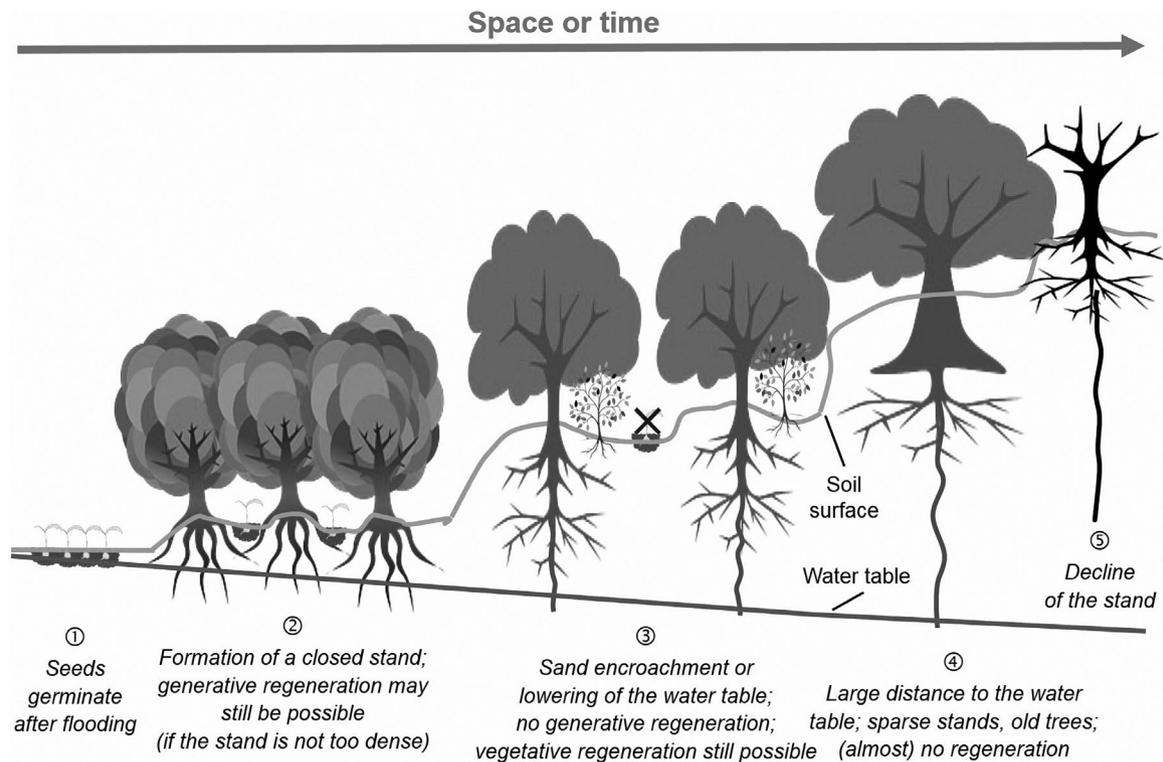


FIGURE 1 Schematic life history of *Populus euphratica* stands at the Tarim River (northern fringe of the Taklamakan Desert) across a sequence of groundwater distances and development stages from flooding and the germination of seeds (①) to exclusively vegetative regeneration (③) and the ultimate decline of the stand at large distances to the groundwater (⑤)

tree (Wiehle, Eusemann, Thevs, & Schnittler, 2009). Thus, large clones can develop that cover areas of up to 121 ha (Vonlanthen, Zhang, & Bruelheide, 2010). However, the trees' capability to regenerate vegetatively through suckers decreases with increasing distance to the water table and is limited to a maximum groundwater distance of ~8 m (Zerbe & Thevs, 2011). Therefore, *P. euphratica* stands growing at a large distance to the groundwater often are relatively old and sparse, whereas dense poplar stands containing a large fraction of young trees generally are only found at sites with a relatively small distance to the water table or to the riverbed (Thomas et al., 2017). When the distance of the trees to the groundwater becomes too large, the stand declines (Figure 1).

This life history of *P. euphratica* stands leads to the assumption that the percentage of clones in a given stand increases with an increase in the distance to the water table because sexual reproduction decreases. In recent studies, however, no straightforward relationships were found between the groundwater distance on one hand and the percentage of clones, the survival and the age of the stands on the other hand. Those studies were conducted at the middle reaches of the Tarim River (Eusemann, Petzold, Thevs, & Schnittler, 2013) and across a larger gradient of site conditions from the lower and the middle reaches of the Tarim River to the Aibi Lake (Ebinur) in the western part of north-eastern Xinjiang (Kramp et al., 2018). These results indicate that the genetic pattern of *P. euphratica* is not easily predictable even over small distances, but is a result of a complex

interplay of stand history and dispersal of propagules (pollen, seeds, and vegetative diaspores) by wind and water. Thus, for the stand structure including its age distribution and the spatial and genetic relationships among the trees, the site history and, in particular, the pace of the decrease in the groundwater level may be at least as important as the lowering of the water table itself. Overall, the genetic diversity of *P. euphratica* across its distribution in north-western China is high (Wang, Li, Guo, Ren, & Wu, 2011). However, pure clonal stands can occur at sites where a high salt concentration of the upper soil prevents germination of the seeds (cf. Zhang et al., 2019) and establishment of the seedlings although the distance to the groundwater is relatively small (1.4–2.7 m; Kramp et al., 2018).

The understory of the riparian forests harbours only some few shrub and herb species, whose number and abundance mainly depend on the distance to the river and to the groundwater and, thus, on the availability of water: species richness and abundance decrease with decreasing water supply (Thevs et al., 2008; Table S1 of the Supporting Information). In general, the alpha diversity of plant species is low along the Tarim River: up to only ~30 vascular plant species have been found in a given plant community on flooded plots at the river's middle (Thevs et al., 2008) and lower reaches (Ling, Zhang, Xu, & Zhao, 2015) with *P. euphratica* and the shrub *Tamarix ramosissima* being the most abundant species. However, some species are important for medicinal use (Li et al., 2016; Table S1 of the Supporting Information).

3 | GROWTH AND BIOMASS PRODUCTION OF RIPARIAN POPLAR FORESTS

In young, dense, and highly productive stands in the Tarim Basin, the total above-ground wood biomass of *P. euphratica* can reach 56 Mg ha⁻¹—similar to the value of 58 Mg ha⁻¹ determined at the middle reaches of the Amu Darya under comparable conditions—but is smaller at larger distances to the groundwater and to the river (Aishan, Betz, Halik, Cyffka, & Rouzi, 2018; Thevs et al., 2012; Thomas et al., 2017; Table 1). Although, in general, vigour (assessed through the extent of defoliation) and growth of *P. euphratica* trees decrease with increasing distance to the groundwater and the river at the stand level (Gries et al., 2003; Halik, Aishan, Betz, Kurban, & Rouzi, 2019; Ling et al., 2015; Table 1), individual mature trees growing at larger distances to the groundwater (up to 12 m) can reach a similar annual productivity as trees of the same age class thriving at shorter distances to the water table (Thomas et al., 2017). Attaining values of up to ~3.3–3.4 Mg ha⁻¹ yr⁻¹ in a young (22 years, originated from clonal growth after clear-cutting; Gries et al., 2005) and a middle-aged stand (Wang et al., 1996) and 2.8 Mg ha⁻¹ yr⁻¹ in a mature stand (Table 1), the annual above-ground wood production (AAWP; sum of trunks, branches and twigs) can exceed the productivity of typical desert vegetation in Central Asia (<1.0 Mg ha⁻¹ yr⁻¹; Walter & Box, 1983).

Along gradients of water supply (distance to the groundwater or supply with additional “environmental flow” for restoration purposes) at two sites (middle and lower reaches of the Tarim River), the average tree-ring width and basal area increment (BAI) during four decades (1971–2011) were significantly higher in stands with the amplest water supply than in the stands with larger distances to the groundwater or smaller water supply (Lang et al., 2016). However, a more thorough analysis of productivity data revealed that, according to the life history of the trees (see section Life history and rejuvenation of riparian poplar forests), AAWP per unit soil-surface area was much

closer related to the age and the density of the stands than to ground-water distances (Thomas et al., 2017).

Around the year 2000, wood harvesting from living *P. euphratica* trees has been banned in any form in several regions of Xinjiang (cf. Bruelheide et al., 2003; Mamat et al., 2019), but in the past, forest productivity has distinctly decreased by intense wood harvesting through stem cutting or pollarding, that is, cutting of branches or large twigs. However, the trees are capable of (partly) compensating the loss of biomass through a more intense gas exchange and formation of secondary branches (Lang et al., 2015). In contrast, a moderate intensity of pollarding does not result in significant growth reduction and should be permitted to let the local population make use of this renewable resource (Lang et al., 2015). In a 22-year-old coppice stand, harvesting of 44–49% of the stems did not lead to a reduction in stem diameter increment, but even to enhanced growth in the subsequent year (Gries et al., 2005). Aboveground biomass productivity can be reduced by complete defoliation upon infestation with larvae of Lepidopteran species, which occurs every few years, and can result in a loss of ~44% relative to years of high productivity at ample water supply (Schäfer, Saleh, Yu, Zhang, & Thomas, 2017).

Supply with additional (“ecological”) water resulted in a marked increase in tree growth (Gärtner, Förster, Kurban, & Kleinschmit, 2014; Lang et al., 2016). Interannual fluctuations in the water supply led to distinct alterations in BAI in trees that grew at a short distance to the water table or were supplied with additional water. At the Tarim River's middle reaches, in the time period 1971–2011, when the course of the river was relatively constant, tree-ring increment and BAI exhibited a significantly positive relationship with the river discharge of the preceding year (which occurs in late summer and autumn, when the annual increment of the trees is already completed [Thomas et al., 2008] and, therefore, exerts no effect on the tree growth in the same year). However, this correlation was restricted to the stand growing at the shortest distance to the groundwater (2 m) and to the river's main course (Lang et al., 2016).

TABLE 1 Structure of riparian poplar stands, above-ground wood biomass (AWB), and soil surface-related annual above-ground wood productivity (AAWP; 3-year average) on plots differing in groundwater distance or water supply at the upper, middle, and lower reaches of the Tarim River (means ± 1 standard error, where applicable)

	Upper reaches (near Xayar)	Middle reaches (near Yingbazar)			Lower reaches (near Arghan)		
Groundwater distance (m)	2.1	2.0	7.5	12.0	5.2 + EW ^a	4.8	6.6
Stand density (trees per ha)	121	467	378	67	166	257	59
Range of tree age (years)	35–91	50–68	39–141	35–314	17–68	29–119	15–162
Tree height (m)	9.8 ± 0.2	10.6 ± 0.3a	7.6 ± 0.1b	5.2 ± 0.3c	7.9 ± 0.2a	6.1 ± 0.1b	4.4 ± 0.2c
AWB (Mg ha ⁻¹)	13.9	55.6	31.3	15.6	28.0	25.6	6.9
AAWP (Mg ha ⁻¹ yr ⁻¹)	0.72 ± 0.01	2.77 ± 0.10 a	1.96 ± 0.03 b	0.30 ± 0.01 c	1.19 ± 0.18 a	1.29 ± 0.01 a	0.28 ± 0.05 b
Annual water use (mm) ^b	n.d.	n.d.	n.d.	n.d.	149.4	80.9	28.0

Notes: Different lower case letters indicate statistically significant differences among plots in a given region (Kruskal–Wallis test followed by post-hoc multiple pairwise Dunn's tests; data from Lang et al., 2015; Lang et al., 2016; Thomas, Jeschke, Zhang, & Lang, 2017). n.d., not determined.

^aEW, supply with additional “ecological water” in most years since 2000.

^bDetermined from xylem sap flow according to Granier, Biron, Bréda, Pontailier, and Saugier (1996).

4 | WATER USE AND WATER USE EFFICIENCY OF RIPARIAN POPLAR FORESTS

Corresponding to the trees' permanent access to the groundwater, the annual water use of *P. euphratica* stands at the lower reaches of the Tarim River (up to 150 mm yr^{-1} ; Table 1) is high compared to typical desert vegetation ($<150 \text{ mm yr}^{-1}$; Larcher, 2003). Even higher transpiration rates were obtained through the Penman-Monteith approach in a 22-year-old coppice stand of *P. euphratica* at the southern fringe of the Tarim Basin (223–392 mm; Thomas et al., 2006) and from sap-flow measurements in a middle-aged (38 years) and old (104 years) *P. euphratica* stand in the hyper-arid Heihe River Basin of northern China with a groundwater distance of up to $\sim 2 \text{ m}$ (283 and 196 mm, respectively; Yu et al., 2019). These high transpiration values are another reliable indicator that *P. euphratica* in those hyper-arid regions must have continuous access to the groundwater not only for establishment, but also for survival and growth. The same conclusion can be drawn from precipitation data and calculations of evapotranspiration for *P. euphratica* forests along the Tarim River (Thevs, Peng, et al., 2015) and the Amu Darya in north-eastern Turkmenistan (Thevs, Ovezmuradov, Zanjani, & Zerbe, 2015). Anatomical and flux investigations on horizontally running underground root sections ("root spacers") of *P. euphratica* that connect ramets originated from vegetative recruitment with their "parent" plants have demonstrated that water supply through those spacers would be sufficient to meet the water demand even of large mature trees (Figure 2; Hoppe et al., 2020).

According to the relatively high transpiration rates, the water use efficiency of above-ground productivity (biomass produced per unit

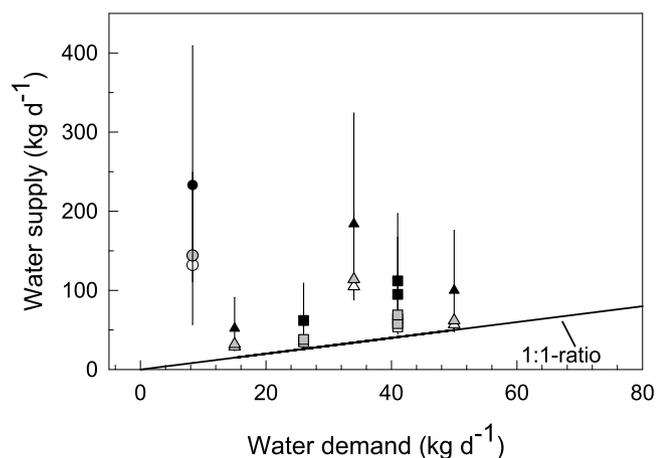


FIGURE 2 Daily water demand per tree in the month with the highest transpiration rates in *Populus euphratica* growing in riparian forest stands at different locations at the fringes of the Taklamakan Desert (circles, 22-year-old coppice stand at the southern fringe of the Taklamakan Desert; triangles, mature stand at the middle reaches; squares, mature stand at the lower reaches of the Tarim River) and calculated water supply through root spacers with different diameters (10.5–12.5 mm, white symbols; 14.5–16.8 mm, grey symbols; 16.9–21.8 mm, black symbols) on the basis of laboratory flux measurements (data from Hoppe, Zhang, & Thomas, 2020)

water transpired) is rather low and, in the 22-year-old coppice stand, does, on average, not exceed $1.6\text{--}2.3 \text{ g DM per kg}_{\text{H}_2\text{O}}$ (Thomas et al., 2006), which is markedly lower than in broad-leaved trees of temperate regions ($3\text{--}5 \text{ g}_{\text{DM}} \text{ kg}_{\text{H}_2\text{O}}^{-1}$; Larcher, 2003).

5 | MANAGEMENT MEASURES AND RECOMMENDATIONS FOR TUGAI FORESTS

Withdrawal of water, mainly for irrigation of agricultural fields along the upper and middle reaches of the Tarim River, as well as water retention through construction of reservoirs in the mountain areas (Chen, Ye, & Shen, 2011) are the main causes of the decline of the riparian forests, particularly at the lower reaches (Chen, 2014; Li, Zhou, Fu, & Chen, 2013; Zu, Gao, Qu, & Qiang, 2003). Therefore, a long-term programme has been launched in 2000 to divert additional ("ecological") water to the river's lower reaches to protect and conserve the remaining forests of that region. From 2000 to 2015, up to 820 million m^3 water per year have been released from the Daxihaizi Reservoir upstream of the river's lower reaches, but only very small amounts have been conveyed in the period 2007–2009 (up to ~ 20 million m^3) and in 2014 (10 million m^3) (Ling et al., 2019).

Along the lower reaches of the Tarim River, forests cover an area of 33,700 ha (Chen, Li, Xu, Ye, & Chen, 2015). Mature *P. euphratica* stands growing at a groundwater distance of $\sim 5 \text{ m}$ and supplied with "ecological water" transpire up to 150 mm yr^{-1} in that region (Table 1), amounting to 50.6 million $\text{m}^3 \text{ yr}^{-1}$ for the entire forest area. This value is similar to the water consumption of 58.6 million $\text{m}^3 \text{ yr}^{-1}$ by forests of that region calculated by Chen et al. (2015) across all water table levels. Of course, stands with the same distance to the groundwater ($\sim 5 \text{ m}$; cf. Table 1), but without additional water supply, would only use 27.3 million $\text{m}^3 \text{ yr}^{-1}$ (or 16.8 million $\text{m}^3 \text{ yr}^{-1}$ according to Chen et al., 2015), and very old and sparse stands with an assumed groundwater distance of 6.6 m (cf. Table 1), only 9.4 million $\text{m}^3 \text{ yr}^{-1}$ (or 13.2 million $\text{m}^3 \text{ yr}^{-1}$ according to Chen et al., 2015) when related to the entire forest area. Nevertheless, according to measurements and calculations, an amount of 160–300 million m^3 is being recommended to meet the water demand of these *P. euphratica* forests, that is, to lift the water table to a distance of 2–4 m below the soil surface (Chen et al., 2010, 2015; Ling et al., 2015), which is considered ecologically suitable for the growth of *P. euphratica* forests (Li et al., 2013). However, for the period 2009–2012, modelling (MIKE HYDRO software; Yu Yang, TU Munich, personal communication) only yielded a maximum discharge of 53.9 million m^3 in 2012 and even a complete lack of river run-off in 2009 for the gauge of Qiala (lower reaches of the Tarim River). Water availability is particularly restricted when water level is low in the Bosten Lake, the main water reservoir upstream of the lower reaches of the Tarim River (Chen et al., 2010). Thus, Aishan et al. (2013) and Halik et al. (2019) have raised caveats on water diversion for environmental flow. Therefore, we recommend that supply with additional ("ecological") water should focus on forest stands with a short distance to the groundwater to keep at least these forests fully functional and to maintain their ability

to regenerate from seeds upon flooding instead of diverting large quantities of water to stands with large distances to the groundwater, which are foredoomed to die off due to a dwindling ability to regenerate. Moreover, successful establishment of seedlings of typical riparian trees depends on the occurrence of bare, moist surfaces protected from disturbance, as has been shown for *P. deltoides* in western North America (González et al., 2018; Scott, Friedman, & Auble, 1996). Along the Tarim River, concentrating additional water supply on forest stands with a short distance to the groundwater gains even more importance by the fact that during the past decades, the course of the river has become more constant due to lower rates of discharge (Thevs et al., 2008) and by embankment upon a large-scale construction of dykes (Halik et al., 2006). This results in progressively smaller zones along the riverbanks in which regeneration from seeds is possible.

Therefore, on the basis of results of Chinese research projects and of a joint German-Chinese research program ("Sustainable Management of River Oases along the Tarim River / China – SuMaRiO"; funded by the German Federal Ministry of Education and Research, 2011–2016; cf. Rumbaer et al., 2015), the following policy recommendations with regard to the *tugai* forests were formulated and communicated to the Chinese authorities:

It is recommended that

- a moderate extent of wood harvesting by pollarding (cutting twigs and branches from trees) is allowed in case of *P. euphratica* growing at a short distance to the groundwater (up to 2 m);
- a continuous and sufficient water supply to *P. euphratica* forests growing at short distances to the groundwater (up to 5–6 m) is ensured instead of diverting water to stands located at large distances to the groundwater.

These suggestions may be integrated in water management schemes that aim at protecting and conserving the unique riparian forest ecosystems in the Tarim River Basin and, simultaneously, allow a sustainable use of the forests. Such a strategy, which also might include active introduction of poplar trees (cf. González et al., 2018), is particularly important against the background of substantial mass losses of the Tian Shan glaciers, which constitute the source of the Tarim River water, due to the current climate change (Farinotti et al., 2015).

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analysed in this study. Available references can be obtained by request to the corresponding author (FMT).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

How to cite this article: Thomas FM, Lang P. Growth and water relations of riparian poplar forests under pressure in Central Asia's Tarim River Basin. *River Res Applic*. 2020;1–8. <https://doi.org/10.1002/rra.3605>