Quaternary International 311 (2013) 146–154

Contents lists available at SciVerse ScienceDirect

Quaternary International

journal homepage: www.elsevier.com/locate/quaint

Influence of sediment, soil, and micro-relief conditions on vitality of *Populus euphratica* stands in the lower Tarim Riparian Ecosystem

A. Ginau [a,*], Ch. Opp [b], Zh. Sun [c], Ü. Halik [d]

[a] Institute of Geography, Department of Geosciences and Geography, Goethe University Frankfurt am Main, Altenhöferallee 1, D-60438 Frankfurt, Germany
[b] Faculty of Geography, Philipps-Universität Marburg, Deutschhausstr. 10, D-35032 Marburg, Germany
[c] State Key Laboratory of Lake Science and Environment, Nanjing Institute of Geography and Limnology, Chinese Academy of Sciences, 73# East Beijing Road, 210008 Nanjing, China
[d] Faculty of Mathematics and Geography, Katholische Universität Eichstätt-Ingolstadt, Ostenstraße 14, D-85072 Eichstätt, Germany

ARTICLE INFO

Article history:
Available online 13 July 2013

ABSTRACT

Excessive withdrawal of water for farmland irrigation, and water losses from water reservoirs and channels, have caused water deficit problems along the Tarim River in Northwestern China. Especially, the lower reaches have been severely threatened since the 1950s, and are experiencing a drastic increase in the mineralisation of the river water. Additionally, large scale deposition of aeolian sand and dust is another major threat for the Tarim Riparian Ecosystem (TaRiEc). This development reached its "climax" with the desiccation of the Taitema Lake in 1972, and the "climax" was well expressed by severe degradation of the TaRiEc, which is in turn predominately characterized by the dying of *Populus euphratica* stands. All these developments led to the initiation of the "Ecological Water Diversion Project" (EWDP). The main objective of this project is to ensure a constant water supply to the lower reaches of the Tarim River via the water transfer both from the Bosten Lake catchment and from Tarim's upper and middle reaches. In this study, the processes and trends of the vegetation change during this period of intermittent water transfer were examined on the basis of remote sensing data. The results show that with the water transfer only some of the *P. euphratica* trees reached a more vital state.

Common hypotheses about factors influencing the tree vitality under stressful conditions deal with the water level in the river, the groundwater level and the distance of the trees from the river. However, soil and sediment, as well as micro-relief conditions also play an important role and take influence on the vitality of the trees. The main objective of the present study was to analyse the features of soil and sediment concerning water passage and water storage processes in near surface and subsurface positions of the lower Tarim Riparian Ecosystem. For that purpose, 2010 and 2011 field and laboratory analyses of soil and sediment profiles were performed. Laboratory results comprise grain size measurements, pore size distribution, total organic content (TOC) and data from XRD-measurements on the soil's mineral composition for all studied sites within the lower Tarim study area and for selected ecosystem types as well. These parameters allow conclusions about water storage and water passage conditions, which play a key role for water availability and water supply of *P. euphratica* trees. Besides single soil and sediment parameters, such as salt content and mineral composition, layer types (vertical sequence of soil horizons and sediment layers) have been identified as leading factors determining near surface and subsurface water passage and water storage features of the Tarim Riparian Ecosystem.

1. Introduction

The Taklimakan Desert belongs to the world's most extreme environments due to its mid-continent location. It is the desert farthest away from any ocean. Additionally, due to the rain-shadow of the Kunlun and Tien Shan mountain ranges (Arndt et al., 2004) it barely receives any rainfall. Within this extreme environment Tugai forests along the Tarim River and its tributaries form a "green corridor", a unique flood plain ecosystem (Thevs et al., 2008). This

* Corresponding author.
E-mail addresses: Ginau@em.uni-frankfurt.de, ginau@em.uni-frankfurt.de (A. Ginau), opp@staff.uni-marburg.de (Ch. Opp), sun@niglas.ac.cn (Zh. Sun), uemuet.halik@ku-eichstaett.de (Ü. Halik).

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http://dx.doi.org/10.1016/j.quaint.2013.06.025

Tarim Riparian Ecosystem (TaRiEc) is predominantly characterised by *Populus euphratica* stands (Chen et al., 2006; Deng, 2007).

In the course of land opening campaigns and excessive use of water for irrigation the Tarim River and the Tugai forests along its reaches have been severely affected by human occupation since the 1950's, (Giese et al., 2006; Chen et al., 2008; Thevs et al., 2008). The loss of river discharge, the regulation of the water level and the increasing mineralisation of the river water are constant threats for this fragile ecosystem. Especially, the Lower Tarim area is severely threatened as it shows the highest reduction in river run-off (Giese et al., 2006). As a consequence, flow into Taitema Lake, the terminal lake of the Tarim River, has dropped to zero since the 1970s and has led to the complete desiccation of the lake accompanied by a severe groundwater drop (Chen et al., 2008), from 7.0 to 12.6 m depth in the Argan study area. With the initiation of the EWDP in 2000 (Xu et al., 2004; Hou et al., 2007), water was delivered from Boston Lake via the Kongqe River and artificial channels into the lower Tarim. According to Sun et al. (2009), nine intermittent water deliveries were carried out between 2000 and 2007. In consequence of the lowering of the Boston Lake level, and of the increased water withdrawal from the upper and middle sections of the Tarim River, water deliveries into the lower Tarim did not take place from 2008 to 2010. Higher amounts of summer rain, a rising level of the Boston Lake, and the reduction of water losses with the help of more efficient irrigation management in the upper and middle sections of the Tarim River, have helped to create conditions which again allowed a water transfer to the lower reaches of the Tarim River 2011 and 2012.

These developments triggered the establishment of several research projects including *EVASTar*, dealing with the vitality of the Tugai forests, and *SuMaRiO* (see: http://www.sumario.de/de). The latter aims to analyse the sustainable management of river oases along the Tarim River. *EVASTar*, a cooperation between the Technische Unversität Berlin and Xinjiang University Urumqi, aims to develop a tool to analyse the revitalization of the Tugai forests and monitor the long-term vegetation changes in the lower Tarim area (Hoppe, 2006). The ecosystem's reaction on a spatial and temporal scale was further analysed by monitoring the vegetation cover conditions via the use of MODIS NDVI time series data (Sun et al., 2009, 2010). Their results show that the series of water deliveries led to a restoration of the ecosystem and especially to the reviving of *P. euphratica* population.

On site monitoring of ground-water flow, mineralisation and plant diversity foster this result. Primarily, the groundwater depth and the distance to the river are important factors controlling the vitality of *P. euphratica*, which is owed to the maximum groundwater depth for the survival of *P. euphratica* of 10–13 m (Thevs, 2005). The positive linkage of the groundwater level to the water deliveries was researched and monitored by Chen et al. (2008). According to their results, the groundwater depth successively lowered from 10–12 m.b.s to 5–3 m.b.s. and successively influenced vitality and species diversity in the Tugai forests along Tarim River (Chen et al., 2006, 2008; Halik et al., 2011b). Nevertheless, field studies showed that small scale differences in the vitality of *P. euphratica* appeared, that cannot exclusively be related to fluctuations of the groundwater level or the distance to the Tarim River. We suggest that variations in the soil underneath explain why different *P. euphratica* sites are edaphically either promoted or degraded. This can be attributed to factors controlling the capability to store, to transport and to protect water in the underlying ground, which left behind a mosaic of sites with different tree vitalities.

The main objective of this study was the analysis and characterisation of the sediment layers (aeolian and fluvial sediments) within the Tarim Riparian Ecosystem (Runge and Ximing, 2004). These layers showed differences in terms of grain sizes, pore volume, mineral composition, humus content and other soil and sediment features, such as salt content and electric conductivity. These parameters control the water passage and water storage features of the sediments and therefore affect the vitality and regeneration potentials of the *P. euphratica* stands within the Tarim Riparian Ecosystem.

2. Study site

This study was conducted near Argan village in the lower reaches of the Tarim River, Xinjiang, China. The lower reaches of the Tarim River cover an area that stretches over a distance of more than 300 km from the Daxihaizi Reservoir (NW) to Taitema Lake (SE) (Fig. 1).

The BWk climate (after Köppen) of the region is extremely dry (continental arid) with a long, hot summer. The annual mean precipitation lies below 50 mm and the annual potential evaporation exceeds 2500 mm. Strong winds blow frequently in the region and cause large-scale sand and dust movements (Chen et al., 2008; Wang et al., 2009).

The Tarim River itself is embedded in wide alluvial fans, separating Taklimakan and Kuluk Desert. The fans result from the constantly changing river morphology that left behind traces of old river branches within the fans. With its course through the alluvial sediments the Tarim River constantly loses water and recharges important groundwater reservoirs. The Tarim is therefore regarded as an influent stream (Fan et al., 2008). According to the study of Chen et al. (2008), which examined groundwater levels along a transect within the study area, the local groundwater level lies between 7 and 10 m b.s.l. and increased during the water deliveries of about 1–2 m.

According to Wang et al. (2009) the composition of the surrounding vegetation changes significantly with increasing distance to the river, due to the lowering of the groundwater level with increasing transverse distance to the river and the fact that especially the areas directly along the river profited from the artificial water input. Therefore, these areas show the highest positive groundwater level changes (Chen et al., 2008). Sites nearing the riverbank are dominated by *P. euphratica* forests and some herbaceous species (esp. *Alhagi sparsifolia, Karelinia caspica, Glycyrrhiza inflata*). Primary shrub species occurring in this area are *Tamarix* spp., *Lycium ruthnicum* and *Halimodendron halodendron*.

As a consequence of the very dry climate, the rate of soil formation is very low. Therefore, soils comprise mainly unweathered mineral material that has been deposited by the Tarim River or blown in by strong long distance winds prevailing in this region.

Partly, these sediments are remobilised and removed by short-distance wind transport. Mostly soils can be described as Arenosols with very low humic contents. Grain sizes often vary throughout the profiles as the depositional milieu constantly varied in the past from fluvial to aeolian deposits. Another important feature altering the sediments is the precipitation of salts within the sediments.

3. Materials and methods

Studies were carried out during two field campaigns in April 2010 and August 2011. Conditions between these two campaigns greatly varied as the first campaign in April 2010 was situated in the very dry spring and the campaign in August 2011 fell within the growing period of the Tugai forest. Accordingly, discharge conditions of the Tarim River varied: no discharge (and a very low groundwater level) in 2010, discharge in 2011 (and a rising groundwater level) in the lower reaches of the Tarim River. Overall, fifteen outcrops were studied, out of which eight outcrops were taken in region N of the *EVASTar* Project and four along a transect crossing the Tarim River in region S (see Fig. 1). Trees in the test