4. Water allocation along the Heihe River and Tugai forest conservation in Ejina

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4.1 Introduction

Tugai forests are the riparian forests of the deserts of Central Asia (Ogar 2003; Treshkin 2001). These forests together with reed beds are the most productive ecosystems of the deserts of Central Asia (Thevs 2007; Thevs et al. 2012) and harbour most of the biodiversity of these deserts (Thevs 2007; Thevs et al. 2008b; Ogar 2003). In the past, Tugai forests were a major wood source and an important pasture in the deserts of Central Asia (Hoppe 1992). During the past five decades, their role to stabilise moving sand has been acknowledged (Song et al. 2000; Yimit et al. 2006). Today, their role with respect to carbon sequestration and groundwater recharge has been attracting more and more attention (Thevs et al. 2012). Tugai forests play an important role with regard to the identity of people in these desert regions (Hoppe 1992; Ejina Qizhe 1998). During the past decade, Tugai forests in Xinjiang and along the Heihe River attract more and more tourists, with Ejina being China's most important tourist destination with respect to Tugai forests (personal observation).

From east to west, these riparian forests naturally are distributed along rivers in northwest China (Inner Mongolia, Gansu and Xinjiang), Mongolia, low-lying river valleys of Kyrgyzstan and Tadzhikistan and in the deserts of Kazakhstan, Uzbekistan and Turkmenistan (Lavrenko 1956; Wang et al. 1996; Ogar 2003). The largest Tugai forests were distributed along the Amu Darya (within Turkmenistan and Uzbekistan) and in the Tarim Basin, China

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with approximately 500,000 ha each in the 1950s (Huang 1986; Treshkin 2001). In China, after the Tarim Basin the second largest Tugai forests naturally were distributed along the downstream section and the delta of the Heihe River in Ejina County, Inner Mongolia. In Ejina, about 430,000 ha are covered with woodland, including Tugai forests (Ejina Qizhe 1998). The Tugai forests in Ejina were described as a green belt in the middle of the desert as early as 1927 by Sven Hedin, who crossed the Heihe River during the Sino-Swedish Expeditions between 1927 and 1935 (Hedin 1943).

After the People’s Republic of China was founded in 1949, oases areas along all rivers in northwest China were enlarged. As agriculture in northwest China largely depends on irrigation, more and more water was diverted from the rivers in Xinjiang, Gansu, Inner Mongolia and other provinces in the north western parts of the country. The Heihe River frequently ceased to reach its two end-lakes, West and East Juyanhai Lakes, so that the West Juyanhai Lake fell dry in 1961, while the East Juyanhai Lake shrunk and fell dry for the first time in 1973 (Ejina Qizhe 1998). Agriculture and animal herding declined, too, due to severe water shortage, resulting in widespread poverty in Ejina County.

In 2000, a water allocation plan was adopted by the Central Government of China, which should ensure a guaranteed annual amount of 0.95 km^3 to be released into Ejina County. One objective of this water allocation plan was to restore the Tugai forests along the Heihe in Ejina. Against this background, we will analyse the current state of the Tugai forests along the Heihe in Ejina and draw conclusions in how far the water allocation plan meets the needs for Tugai forest conservation. We will analyse the state of the Tugai forests according to the criteria for forest quality by IUCN and WWF in 1996 (WWF and IUCN 1996). The assessment of the forests is based on two field visits in 2011 and 2012.

4.2 Ecology of Tugai Forests

Tugai forests are the riparian forests distributed along the rivers, which flow through the deserts of Central Asia, e.g. Amu Darya, Syr Darya, Chu, Ili, Irtysh, Tarim and Heihe (Wang et al. 1996; Treshkin 2001; Ogar 2003). The Tugai forests are formed by the Poplar species *Populus euphratica* and *P. pruinosa*, willow species, like *Salix acmophylla* and *S. soongorica*, and *Elaeagnus angustifolia* (CMF 1990; Wang et al. 1996; Ogar 2003). The understory vegetation is dominated either by shrubs, i.e. *Tamarix* species, *Halimodendron halodendron*, *Lycium ruthenicum*, *Nitraria sibirica* and partly by halophytes, or by *Phragmites australis* and herbs like *Glycyrhizza glabra* and *Alhagi sparsifolia* (Wang et al. 1996; Thevs et al. 2008a). *Salix* species are restricted to Tugai forests along the rivers in the Zhunggar Basin (Xinjiang), Ili Basin and the Aral Sea Basin (CMF 1990; Wang et al. 1996; Ogar 2003). *H. halodendron* is much more frequent along the Syr Darya and Ili compared to the Tarim and Heihe. In addition, the herb layer is more diverse in the Zhunggar Basin (Xinjiang), Ili Basin and the Aral Sea Basin compared with the Tarim Basin and the Heihe River Basin (Wang et al. 1996).

P. pruinosa is distributed throughout the Tugai forest area, but it is restricted to more humid, less saline, and less winter-cold sites compared to *P. euphratica*. Thus, *P. pruinosa* is neither found in the downstream region of the Amu Darya and Syr Darya, nor in the eastern part of the Tarim Basin, nor in the northern part of the Heihe River Basin, which corresponds to Ejina County (Wang et al. 1996). In all these three regions without *P. pruinosa*, the Tugai forests are built by *P. euphratica* with some minor stands or individuals of *E. angustifolia* (Huang 1986; Wang et al. 1996; Ejina Qizhe 1998; Treshkin 2001; Thevs et al. 2008a). In these three regions, most Tugai forests have only sparse or do not have any understory vegetation. Only on sites, which are submerged during flood events or which are located very close to river courses, understory vegetation is found.

Tugai forests in Ejina thus practically are *P. euphratica* forests without undergrowth or in parts with understory vegetation of mainly *Tamarix* species and *P. australis*. The plants of these riparian ecosystems survive under the arid climate, because they take up water from the groundwater as obligate or facultative phreatophytes (Sukhova & Gladyshev 1980; Huang 1986; Xinjiang Linkeyuan Zaolin Zhisha Yanjiusuo 1989; Ogar 2003; Rüger et al. 2005; Thevs et al. 2007, 2008a). *P. euphratica* and *P. australis* are obligate phreatophytes, i.e. these species must have continuous contact to the groundwater (Gries et al. 2003; Thomas et al. 2006). In contrast, *Tamarix* species are facultative phreatophytes and thus are able to survive a certain period disconnected from the groundwater, but using soil moisture from the unsaturated zone (Smith et al. 1998).

Once established, *P. euphratica* can grow on sites with the groundwater level as deep as 12 m (Kuzmina & Treshkin 1997; Novikova 2001; Thevs 2007; Thevs et al. 2008a). *Tamarix ramosissima*, one of the most widely distributed *Tamarix* species, also grows on groundwater level as deep as 12 m (Thevs et al. 2008a). *P. australis* is distributed on sites with groundwater levels not deeper than 3 m (Huang 1986; Liu et al. 1990; Novikova 2001; Thevs 2007). The majority of other species, which may occur in the undergrowth of Tugai forests, is restricted to sites with groundwater levels not deeper than 5 m (Thevs et al. 2008a). The groundwater is replenished by the river courses; therefore, the groundwater levels drop when moving from the riverbanks away from the river (Hou et al. 2007). According to deeper and deeper groundwater levels, the number of plant species, which occur in a Tugai forest, decreases with increasing distance from the river course (Thevs et al. 2008a).

With regard to recruitment, *P. euphratica* follows two strategies, i.e. generative and vegetative recruitment. Generative recruitment depends on flood events and river dynamics (Wang et al. 1996; Thevs et al. 2008a; Wiehle et al. 2009; Eusemann et al. 2013). The seeds are light, have pappus-like hairs, and are dispersed by wind and water. The main fruiting period is between July and September, i.e. during the flood period of the rivers in the distribution area of *P. euphratica*. Optimal germination occurs under conditions of intensive sun radiation, a temperature between 25 and 30 °C, and water-saturated soils with a salt content lower than 0.2 %. Such sites are created by the annual summer floods and shifting river courses. Germination occurs in lines or narrow strips marking flood water lines on the riverbanks (CMF 1990; Liu et al. 1990; Eusemann et al. 2013). After germination, the seedlings invest more in root growth than in shoot growth in order to secure water uptake during the spring and early summer of the following year.

During spring of the year following a germination event, the groundwater level under the seedlings and soil moisture in the root zone of the seedlings drop. Often, the seedlings die, because the roots lose contact to the groundwater and cannot take up enough water from the dwindling soil moisture. Therefore, it is crucial that in the year after germination there is another flood event, which starts in time and reaches a water level so high that the groundwater is lifted into the root zone of the seedlings, but not too high that the seedlings are not drowned. Once the roots of a seedling have grown so deep that they tap the groundwater under the riverbank the whole year round, we call the seedling established. Most likely, a heterogeneous soil structure of sand, silt, and thin silty-clayey soil horizons helps seedlings to survive, because the silt and silty-clayey soil horizons keep more plant available soil moisture than sand so that the seedlings may take up water during spring of the year after germination. The silty-clayey soil horizons must not be too thick or too clayey, because the seedlings' roots cannot penetrate such horizons (Thevs et al. 2008a). After a seedling is established, its root system develops horizontal roots, from which root suckers emerge.

On sites out of the reach of the floods, *P. euphratica* only is able to recruit from root suckers, which emerge from the lateral roots, i.e. through clonal reproduction. These clones can cover areas of 4 ha (Bruelheide et al. 2004). As the parent trees supply the root suckers with water until they reach the groundwater by themselves, vegetative recruitment is restricted to sites on which *P. euphratica* does not suffer water stress. In general, these are sites with a groundwater level not deeper than 6 m (Thevs et al. 2008a).

Under natural conditions, which include regular flood events and river dynamics, the life cycle of a *P. euphratica* Tugai forest can be characterised as follows (Thevs et al. 2008a, 2008b; Wiehle et al. 2009; Eusemann et al. 2013): *P. euphratica* and other species germinate at a river bank after a flood event. *P. euphratica* and other species are able to establish. It also forms larger and contiguous forests with its root suckers. Other species form the undergrowth. As the river dynamics continues to relocate the river branch, at which bank this forest has formed, the river branch may either erode the area of this forest site or it may move away from this forest site. If the river branch moves away from that forest site, the groundwater level will gradually drop. The plant species have to grow deeper and deeper roots following the groundwater. According to their respective ability to do so, the plant species will survive or disappear from this particular forest site. In the course of dropping groundwater levels, the salt content of the groundwater may increase. Increasing salinity results in more species that disappear from this forest site. Therefore, within the succession of Tugai forests species disappear but no new species can enter the succession. Along old and permanently dry river branches, pure *P. euphratica* Tugai forests are distributed without any other species as undergrowth. Under more saline conditions, *P. euphratica* disappears and only *Tamarix* and halophytes may remain.

P. euphratica forests have an annual biomass increase of aboveground woody biomass of up to 1.5 t/ha * a (2.5 t/ha * a on extremely productive sites), as calculated on the basis of tree ring widths (Xinjiang Linkeyuan Zaolin Zhisha Yanjiusuo 1989). Thevs et al. (2012) found biomass stocks (above- and belowground) of up to 44 and 58 t/ha and annual increments of 1.3 and 2.6 t/ha * a in the Huyanglin Nature Reserve at the Tarim River and the Amu Darya State Reserve in Turkmenistan, respectively. The site at the Tarim River has a groundwater level of 3.5 m below surface and a tree density of 379 trees per hectare with an average DBH of 20.2 ± 13.8 cm. The respective site in the Amu Darya State Reserve has a groundwater level of 1.9 m below surface and a tree density of 964 trees per hectare. The average DBH was 14.1 ± 6.4 cm. The annual water consumption of *P. euphratica* forests like at the former and latter site are 554 – 725 mm (Thevs et al. 2013) and 907 – 1043 mm (Thevs et al. 2014), respectively. The annual water consumption of *P. euphratica* on a site at the Heihe in Ejina, whose average age is 25 years with a canopy density of 0.8 %, an average tree height of 10 m, and average diameter at breast height of 12 cm, was 447 mm (Hou et al. 2010).

4.3 Water allocation along the Heihe River

The Heihe River Basin, with an area of 120,000 km², is the second largest endorheic river basin of China (Li et al. 2012b). The headwaters of the Heihe River are located in the Qilian Mountains in Gansu Province south of the city of Zhangye. The Heihe ended in the two terminal lakes West and East Juyanhai close to the border of Mongolia (Figure 1, Chapter 2). At the gauging station Yingluoxia, the Heihe flows out of the Qilian Mountains into the oasis of Zhangye with its population of about 1.3 million people. Within the area of Zhangye, about thirty small rivers flow down from the Qilian Mountains, which now are diverted into irrigation. Only during spring or high flood events some of these rivers reach the Heihe. Once the Heihe leaves Zhangye, it flows as a so-called losing stream through mainly gravel deserts northwards from Gansu into Inner Mongolia. Downstream of Zhangye the Heihe passes the gauging station Zhengyixia. From this station, the Heihe passes the small oasis Jinta and flows into Ejina County in Inner Mongolia. About half way between Zhengyixia and the terminal lakes there is the gauging station Langxinshan. There, the Heihe splits into two branches flowing into West and East Juyanhai Lake, respectively (Qi & Luo 2005) as shown in Figure 1, Chapter 2. Until the 1960s, the two branches branched off further and formed an inland delta.

Table 1 – Aggregated climatic data of Zhangye and Ejina from 1973 to 2012, sourced from TuTiempo.net.

Climate station	Zhangye	Ejina
Position	38.93 °N, 100.43 °E	41.95 °N, 101.61 °E
Elevation [m a.s.l.]	1,483	941
Annual mean temperature [°C]	8	9.4
January mean temperature [°C]	-9	-10.7
July mean temperature [°C]	22,1	27.2
Annual precipitation [mm]	170	60

The climate in the Heihe River Basin is arid and continental, as shown in Table 1. In the Qilian Mountains along the headwaters of the Heihe River, the annual precipitation is about 400 mm. At the foothills of the Qilian Mountains, i.e. climate station Zhangye, it drops to 170 mm and further north in Ejina it decreases to 60 mm (Table 1). About two thirds of the annual precipitation is concentrated in the months June to August. This precipitation maximum falls together with the snow and glacier melting period in the Qilian Mountains, which results in annual summer floods in the Heihe River (Figure 1). Table 2 shows the development of cropland along the Heihe from the 1970s to today. The composition of crops in Zhangye is given in Table 3. Cropland also was reclaimed in Ejina County.

Table 2 – Area of cropland [ha], including fallow and planted forests, digitised from Landsat satellite images.

Administrative unit	Area of cropland [ha], including fallow and planted forests in the year			
	1975	1990	2000	2010
Zhangye	172,388	283,827	323,240	369,336
Jinta	14,996	28,504	42,024	56,826
Jiayuguan	40,749	67,952	105,540	117,726
Ejina	1,540	3,454	3,040	9,130

This increase of cropland area resulted in an increasing demand for irrigation water, which was diverted from the Heihe River. The annual runoff at the gauging station Zhengyixia decreased from 1.19 km^3 in the 1950s over 0.942 km^3 in the 1980s to 0.475 km^3 between 1990 and 1995 (Feng & Cheng 1998). Thus, the Heihe downstream of Zhengyixia faced severe water shortage. The terminal lake West Juyanhai has been dry since 1961 and most of the western branch of the Heihe in Ejina has been dry, too. The terminal lake East Juyanhai Lake covered 35.5 km^2 in 1958, shrunk to 23.6 km^2 in 1980, and dried up in the beginning of the 1990s (Ejina Qizhe 1998). In 2002, it reappeared for a few months with an area of 12 km^2 (Wang et al. 2002). In the course of decreasing runoff reaching Ejina County, soil salinisation increased in parts of the county (Qi & Cai 2007). Groundwater levels dropped from 0.5 – 1.3 m in the 1940s to 3 – 6 m in the 1990s (Guo et al. 2009). However, the runoff from the Qilian Mountains, recorded at the gauging station Yingluoxia, has not changed significantly for the past 50 years despite of global warming and shrinking glaciers in other mountains in China and Central Asia (Jiang & Liu 2010).

Table 3 – Composition of crops and area per crop in Zhangye in 2012, sourced directly from the Agriculture Administration, Zhangye.

Crop	Area [ha]	Crop	Area [ha]
Seed corn	66,700	Pear and apple	5,300
Potatoes	26,700	Apricot	3,300
Vegetables	26,700	Grapes (for wine)	3,300
Rape	26,700	Cotton	2,000
Wheat	20,000	Grapes (for raisins)	2,000
Dates	10,000	Peach	700

In the course of increasing water shortage along the Heihe in Ejina, the natural riparian ecosystems were severely degraded and rural livelihoods were affected (Jin et al. 2010). The area covered by *P. euphratica* forests was 50,000 ha in the 1950s, shrunk to 22,667 ha in 1998, and increased to 38,663 ha by 2004 due to restoration measures (Lu et al. 2007; Bai et al. 2008). During the 1990s, this area of degraded vegetation was made responsible for dust storms, which affected the region, but also other parts of China (Feng & Cheng 1998). Especially the Tugai forests were considered able to significantly reduce dust storms in Ejina proper and beyond, if restored (Guo et al. 2009).

In 2000, an integrated water resource management of the Heihe River Basin was established. In the frame of this integrated water resource management a water allocation plan between the middle and the lower reaches, i.e. between Zhangye and downstream of Zhangye, was adopted. This water allocation plan starts with an average runoff of 1.58 km^3/a at Yingluoxia. An annual runoff of 0.95 km^3 must pass Zhengyixia gauging station and flow into the lower reaches. According to Zhang et al. (2011), the average annual runoff from 2000 to 2009 was 0.995 km³ at Zhengyixia and 0.53 km³ at Langxinshan. The annual runoff of 0.53 km³ at Langxinshan, which is equivalent to the amount of water that Ejina receives, lies above the annual evapotranspiration of the whole cropland and riparian ecosystems within Ejina. More water was guided into the eastern river branch of the Heihe compared to the western branch so that the reed and shrub vegetation around the East Juyanhai Lake started to recover (Guo et al. 2009). While before 2000 the major crops along the Heihe were cotton and paddy rice, now the major crop is seed corn. Most of the seeds, which are used to crop corn in China, are produced in Zhangye. The water consumption of corn in Zhangye is well within the range of other measurements from China. The further crops in Zhangye are listed in Table 3. This shift of crops away from the water demanding paddy rice and cotton enabled to attain a runoff at Zhengyixia according to the water allocation plan. However, the annual amounts of water, which pass Zhengyixia and Langxinshan, fulfil the requirements of the water allocation plan; the runoff distribution within the years has been changed compared to natural conditions. This is shown in Figure 1.

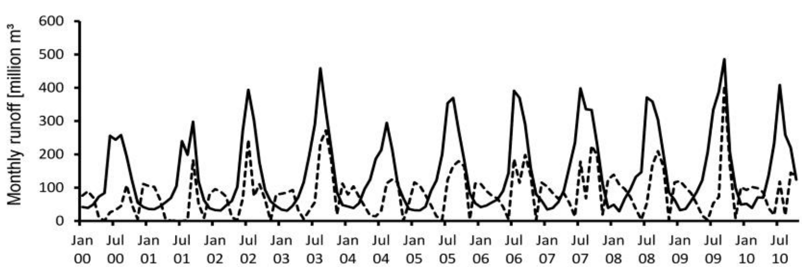

Figure 1 – Monthly runoff of the Heihe River at the gauging stations Yingluoxia (solid line) and Zhengyixia (dashed line), sourced from the Environmental Protection Administration, Zhangye.

While the runoff at Yingluoxia shows clear peaks during the summer months, at Zhengyixia there are two runoff peaks, one in late summer/autumn and another one in winter/early spring. During summer, when the agriculture in Zhangye and other oases has the highest demand for irrigation water, the irrigation demand is covered with water from the Heihe and no water is left for the lower reaches. In autumn and winter/early spring, when irrigation is scaled back and irrigation has not started yet, respectively, water is not needed by the oases along the middle reaches so that water is released into the lower reaches.

4.4 Quality of the Tugai forests in Ejina

The IUCN and WWF developed a set of criteria (Table 4) to evaluate the quality of forests (WWF and IUCN 1996). In this section, we will apply these criteria to assess the quality of the Tugai forests in Ejina against the background of the water allocation plan from 2000. We refer to our own field observations and literature.

Table 4 – IUCN and WWF criteria for forest quality (WWF and IUCN 1996).

Authenticity	Forest health	Environmental benefits	Other social and economic benefits
- natural composition of trees and other species - natural spatial variation of trees with respect to age, size, and proportion of dead timber - continuity - accommodation of natural disturbance patterns within forest management - integration of forest into the landscape - management practices which mimic natural ecological processes	- impacts of air pollutants - robustness to global climate change	- biodiversity conservation - soil and watershed protection - local climatic effects -carbon sequestration	- timber products - non-timber products - support for local industries - recreational value - forest as homeland for people - aesthetic values - historical values - cultural values - educational values - spiritual values - local distinctiveness

4.4.1 Authenticity

The natural tree species composition of the Tugai forests in Ejina consists of *P. euphratica* as nearly the only forest building tree (Photograph 2 to 5) with some stands or individuals of *E. angustifolia*. The Tugai forests today meet this species composition. Furthermore, the forests are associated with *Tamarix* sp. and *P. australis*, which correspond to the natural species composition. Under *P. euphratica* on sites within a distance of 500 m from the two river branches of the Heihe in Ejina, the groundwater levels now are in the range of 1.5 – 3.85 m below surface (He & Zhao 2006; Liu et al. 2007a; Zhu et al. 2009). These groundwater levels fully support the growth and clonal reproduction of *P. euphratica* as well as *Tamarix* and most other potential understory plant species (Thevs et al. 2008a). Only at the downstream section of the eastern branch, the groundwater level was 4.7 m (Guo et al. 2009), which still well sustains *P. euphratica* as well as *Tamarix* (Thevs et al. 2008a). From 2000 to 2005, within 500 m of the river branches the annual increments of *P. euphratica* increased significantly compared to before the year 2000 (Guo et al. 2009), reflecting that groundwater conditions are sufficient to sustain the existing Tugai forests.

Natural stands of *P. euphratica* had a mean age of 141 years, with a minimum of 60 years and maximum of 300 years. The mean tree density was 380 trees per ha. Only planted and semi-natural stands had mean ages of 29 years and 26 years, respectively (Li et al. 2010a). Thus, comparing these natural stands of *P. euphratica* with natural stands along the Tarim River (Thevs et al. 2012) the natural Tugai forests in Ejina are over-aged. By now, natural rejuvenation through root suckers occurs in some *P. euphratica* stands (Photograph 2). Dead timber is present in these natural stands (Photograph 3).

P. euphratica is distributed along both river branches in Ejina within 500 m away from the river branches (He & Zhao 2006). Nevertheless, the Tugai forests do not cover completely these 500 m belts at both sides of the river branches. The Tugai forests are distributed like elongated islands along the river branches. Contiguous *P. euphratica* stands are present and well integrated into the landscape (Photograph 4 and 5). However, small river branches of the previous inland delta of the Heihe in Ejina do not carry water. Therefore, the size and continuity of the Tugai forests lag behind natural conditions (Guo et al. 2009).

The utmost important natural disturbance patterns for Tugai forests are flood events during summer and river dynamics, because they are crucial drivers for the recruitment and development of Tugai forests. Flood events during summer have not occurred since adopting the water allocation plan. Instead, the runoff into Ejina is in autumn and winter. Photograph 2 shows a site, which had been flooded during the previous winter. Liu et al. (2007) found that the water supply in winter has negative impact on annual increments of *P. euphratica* in Ejina.

The two river branches of the Heihe in Ejina have also not been reworked by river dynamics since the year 2000. Summer floods and river dynamics are not mimicked through forest management measures. Therefore, the Tugai forests in Ejina lack generative reproduction and thus conservation of genetic diversity. Artificial rejuvenation of *P. euphratica* has been taken place during the past four decades (Li et al. 2010a), probably with root suckers. However, in how far genetically diverse root suckers have used is not known to us.

4.4.2 Forest health

Air pollution from industry does not occur in Ejina, which is a remote rural community. Dust may play a role, as it covers the leaves and may reduce solar radiation. However, the importance of dust as factor, which may impair the growth rates of *P. euphratica*, lags far behind sinking groundwater and groundwater salinisation.

The robustness or vulnerability to climate change of the Tugai forests in Ejina are decided in the headwaters of the Heihe River in the Qilian Mountains. If climate change altered the runoff regime of the Heihe, it would affect the Tugai forests, because their water supply source exclusively is groundwater, which is delivered by the Heihe. The runoff from the Qilian

Mountains, recorded at the gauging station Yingluoxia, has not changed significantly for the past 50 years despite of global warming and shrinking glaciers as reported from other mountains in China and Central Asia (Jiang & Liu 2010).

4.4.3 Environmental benefits

The two criteria environmental benefits and other social and economic benefits reflect the ecosystem services as widely accepted today (MEA 2005; TEEB 2010). Environmental benefits by WWF and IUCN (1996) refer to regulatory and supporting ecosystem services as understood by MEA (2005). Tugai forests in Ejina provide habitat for wildlife (Ejina Qizhe 1998) as well as Tugai forests all over their distribution area (Wang et al. 1996). The Tugai forests in Ejina are strictly protected and large parts of the forests close to the river branches are fenced. Unfenced forested areas offer unrestricted habitat for birds and other wildlife and decrease environmental pressures from human intrusion. The natural and the planted *P. euphratica* stands play an important role to fix sand and thus reduce dust pollution and improve the local climate. Therefore, the Tugai forests in Ejina contribute significantly to soil protection.

Tugai forests in general are among the most productive ecosystems in the deserts of Central Asia (Thevs et al. 2012). Due to the arid climate, deadwood presumably decays slowly so that Tugai forests should sequester some carbon. However, in how far carbon remains in such ecosystems has not been systematically investigated yet (Thevs et al. 2011). On a local scale, they thus may play a role with respect to carbon sequestration, but due to their small total area, their global role is very limited.

4.4.4 Other social and economic benefits

Other social and economic benefits refer to provisioning and cultural ecosystem services (MEA 2005). The provisioning and cultural ecosystem services of the Tugai forests in Ejina centre on recreation and tourism. Ejina has become a major tourist destination of northwest China with almost 200,000 visitors per year. The visitors travel to Ejina in September and October, in order to see the Tugai forests in autumn due to their aesthetic value and their local distinctiveness. The Tugai forests in Ejina are the most visited Tugai forests in China. Tourists often combine a visit to Ejina with visits to the ancient city Heicheng and the western end of the Chinese wall in Jiayuguan. In this respect, to some extent historical values are attributed to the Tugai forests as part of an area with historical value.

The vegetation and water resources along the Heihe before and after adopting the water allocation plan have been intensively researched by Chinese and some international scholars. Therefore, the Heihe, including the Tugai forests in Ejina, is well known to the scientific community and partly beyond as a showcase for a water allocation plan in a closed river basin. In this context, the Tugai forests contribute to the educational value of the whole region. Today, the Tugai forests are strictly protected so that there are no people living in these forests and no products are made from the timber. Additionally, *P. euphratica* wood has a poor quality as timber as well as fuel wood so that in northwest China *Populus alba* is much more attractive as timber.

4.5 Conclusion

The Tugai forests in Ejina under the current water management serve as a basis for tourism and recreation of significance for whole China and thus create income for people in Ejina. The forests help improving the local climate through sand fixation and reduction of dust storms. Furthermore, the Tugai forests presumably may sequester carbon. The natural species composition is present under the current water management. The annual increments have increased and in some areas natural rejuvenation has started so that the age structure slowly changes from over-aged to diverse. However, the rejuvenation is restricted to clonal reproduction. Under the current water management, the genetic diversity cannot be protected on the long run. Either more water must be released from Zhangye in summer during peak demand of irrigation or seedlings must be grown artificially and planted along the Heihe.

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