Response of riparian vegetation to water-table changes in the lower reaches of Tarim River, Xinjiang Uygur, China

Yaning Chen · Zhonghe Pang · Yapeng Chen · Weihong Li · Changchun Xu · Xinming Hao · Xiang Huang · Tianming Huang · Zhaoxia Ye

Abstract The lower reaches of Tarim River in the Xinjiang Uygur region of western China had been dried out for more than 30 years before water began to be diverted from Konqi (Peacock) River via a 927-km-long channel in year 2000, aimed at improving the riparian ecological systems. Since then, eight intermittent water deliveries have been carried out. To evaluate the response of riparian vegetation to these operations, the groundwater regime and vegetation changes have been monitored along the 350-km-long stem of the river using a network of 40 dug wells at nine transects across the river and 30 vegetation plots at key sites. Results show that the water table rose remarkably, i.e. from a depth of 9.87m before the water delivery to 3.16m after the third water delivery. The lateral distance of affected water table extended to 1,050m from the riverbank after the fourth water delivery. The riparian vegetation has changed in composition, type, distribution, and growing behavior. This shows that the water deliveries have had significant effects on restoration of riparian ecosystems.

Résumé Les parties inférieures de la Tarim River dans la région de Xinjiang Uygur de Chine occidentale ont été asséchées il y a plus de 30 ans avant que de l'eau n'ait commencé à être dérivée de la Konki (Peacock) River par un canal long de 927 km en l'an 2000, destinée à améliorer les systèmes écologiques rivulaires. Depuis lors, huit fournitures intermittentes d'eau ont été effectuées. Afin d' évaluer la réaction de la végétation rivulaire à ces opérations, les modifications du régime de la nappe et de la végétation ont été suivies le long du cours de la rivière long de 350 km en utilisant un réseau de 40 puits au niveau de neuf sections transversales de la rivière et 30 parcelles de végétation à des emplacements clés. Les résultats montrent que la nappe s'est élevée de façon remarquable, i.e. d'une profondeur de 9.87 m avant la fourniture d'eau à 3.16 m après la troisième fourniture d'eau. La distance latérale à laquelle la nappe est affectée s'étendait à 1050 m de la rive de la rivière après le quatrième fourniture d'eau. La végétation rivulaire a changé de composition, de type, de répartition et de comportement de la croissance. Ceci montre que les fournitures d'eau ont eu des effets significatifs sur la restauration des écosystèmes rivulaires;

Resumen Los tramos inferiores del Río Tarim en la región de Xinjiang Uygur (oeste de China) se han secado durante más de 30 años antes que el agua comenzó a ser desviada desde el Río Konqi (Peacock) por medio de un canal de 927 km en el año 2000, con el propósito de mejorar el sistema ecológico ribereño. Desde entonces, se han instrumentado ocho entregas intermitentes de agua. A fin de evaluar la respuesta de la vegetación ribereña a tales operaciones, el sistema de agua subterránea y los cambios en la vegetación han sido monitoreados a lo largo de 350 km del río usando una red de 40 pozos cavados en nueve transectas que atraviesan el río y 30 parcelas de vegetación en sitios clave. Los resultados muestran que el nivel del agua ascendió considerablemente, desde una profundidad de 9.87 m antes de las entregas de agua hasta

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3.16 m después de la tercera entrega. El acuífero ha sido afectado hasta una distancia de 1050 m desde la orilla del río después de la cuarta entrega de agua. La vegetación ribereña ha cambiado su composición, tipo, distribución, y comportamiento de crecimiento. Esto demuestra que las entregas intermitentes de agua han tenido efectos significativos en la restauración de los sistemas ecológicos ribereños.

Keywords Ecology · Water diversion · Riparian vegetation · Tarim River · China

Introduction

Natural vegetation in arid areas plays a very important role in conservation of biodiversity and reduction of desertification. In arid areas, biological activity is limited and ecosystems are small and unstable, and change in the water table directly influences the development and composition of vegetation. These factors in turn affect the fragile ecosystem (Lammerts et al. 2001; Chen et al. 2006; Doble et al. 2006). When other ecological factors do not constrain plant growth, there is an optimal groundwater level above which vegetation may develop fully, and below which the growth of plants is significantly limited. Vegetation may die if such conditions last for an extended period of time (Rey Benayas et al. 1990; Stromberg et al. 1996; Munoz-Reinoso 2001). Nevertheless, the relationship between change of groundwater level and vegetation status is complicated, representing a dynamic equilibrium between groundwater, soil, and vegetation. This relationship has become a key issue in the worldwide study of water resources in arid regions (Kite and Webster 1989; Caldow and Racey 2000). The relationship between vegetation and groundwater has been studied by many researchers (Wassen et al. 1990; Rey Benayas et al. 1990; Ross et al. 1994; Stromberg et al. 1996; Munoz-Reinoso 2001; Chen et al. 2003a, b; Naumburg et al. 2005; Eamus et al. 2006); suggestions have also been made to re-establish hydro-geomorphic regimes by restoring appropriate surface water flow so that groundwater is well sustained (Rood et al. 2005; Stromberg et al. 2007). In order to achieve these goals, it is necessary to improve the understanding of the vegetation's response to a changing water table as a result of river water deliveries, and the extremely arid area in western China is a good test site for this purpose.

Tarim River, 1,321 km in length, is the longest inland river in China with dual features of abundant natural resources and fragile eco-environment. Xinjiang Uygur is well known to the world for its contrasting regional geographic characteristics and severe water resource and ecological problems. In the last 50 years, under the impact of intensive anthropogenic activities centered on water exploitation and utilization, the natural ecological processes have experienced major changes, and the conflicts between economy and ecology over water use have become increasingly stronger than before.

In the lower reaches of Tarim River, the surface ecosystems dominated by natural vegetation have been affected severely by the over use of water resources in the upper reaches of the river. Runoff in the mainstream catchment of the Tarim River has greatly reduced since the 1970s, and runoff at Qiala station has been reduced by 80% over the last 50 years. Annual runoff has decreased from $13.53\times10^8 m^3$/year in the 1960s to $2.67\times10^8 m^3$/year in the 1990s. Flow into Taitema Nor, at the lower end of the Tarim River, has dropped to zero since 1970s and the lake dried up completely in 1972. Correspondingly, the depth of groundwater has increased from 3–5 m to 8–12 m over the past decades (Chen et al. 2003a, b). Natural vegetation maintained by the groundwater has been significantly degraded. Some herbaceous communities such as *Phragmites communis*, *Poacynum hendersonii*, and *Alhagi sparsifolia* have disappeared and amounts of *Tamarix spp*. and *Populus euphratica* have significantly reduced across a large area (Liu and Chen 2005). Wind erosion and sand movement have increased, accelerating desertification and destroying natural ecosystems. The forest area has fallen by 200,000 km^2, grassland has decreased by 850,000 km^2 since the 1950s, and the area of desertification has increased from 1,371 km^2 in 1959 to 1,524 km^2 in 1999. As a result, the so-called “Green Corridor”, in the lower reaches of Tarim River between Taklimakan Desert and Kuluk Desert (Fig. 1), has rapidly declined.

With the recent rapid development of the economy in the study area, potential ecological impacts related to the changing hydrological regime are of great concern to both the general public and the water authorities. The lower reaches of Tarim River are located in a zone between Taklimakan and Kuluk Deserts, where vegetation thrived in the past. Hence, it has been called the Green Corridor. National Highway No. 218 runs through the area, and the Xinjiang-Qinghai railway will also pass through this corridor. In an attempt to rescue the shrinking Green Corridor, water has been diverted to the 320-km dried-up watercourse since year 2000.

Naturally, Tarim River was a perennial river though the flow was very low during the dry season. The water deliveries have not been timed to correspond with the natural high flow period of the river but instead have been targeted to raise the water table. The diversion strategies included the creation of floods which covered a much wider zone on both banks of the river channel, though it was not a full-scale recovery of the natural flow regime. The water table declined between two water delivery events, but there has been a trend of overall rise to reach the targeted depth in the last 6 years.

This report presents an analysis of monitoring data, with emphasis on the response of the riparian ecosystems to water-table changes in terms of vegetation type, distribution and growing properties, the process of response to the water deliveries, and relations between groundwater and vegetation, while aiming to provide a scientific basis for the ecological restoration of arid and semi-arid areas.

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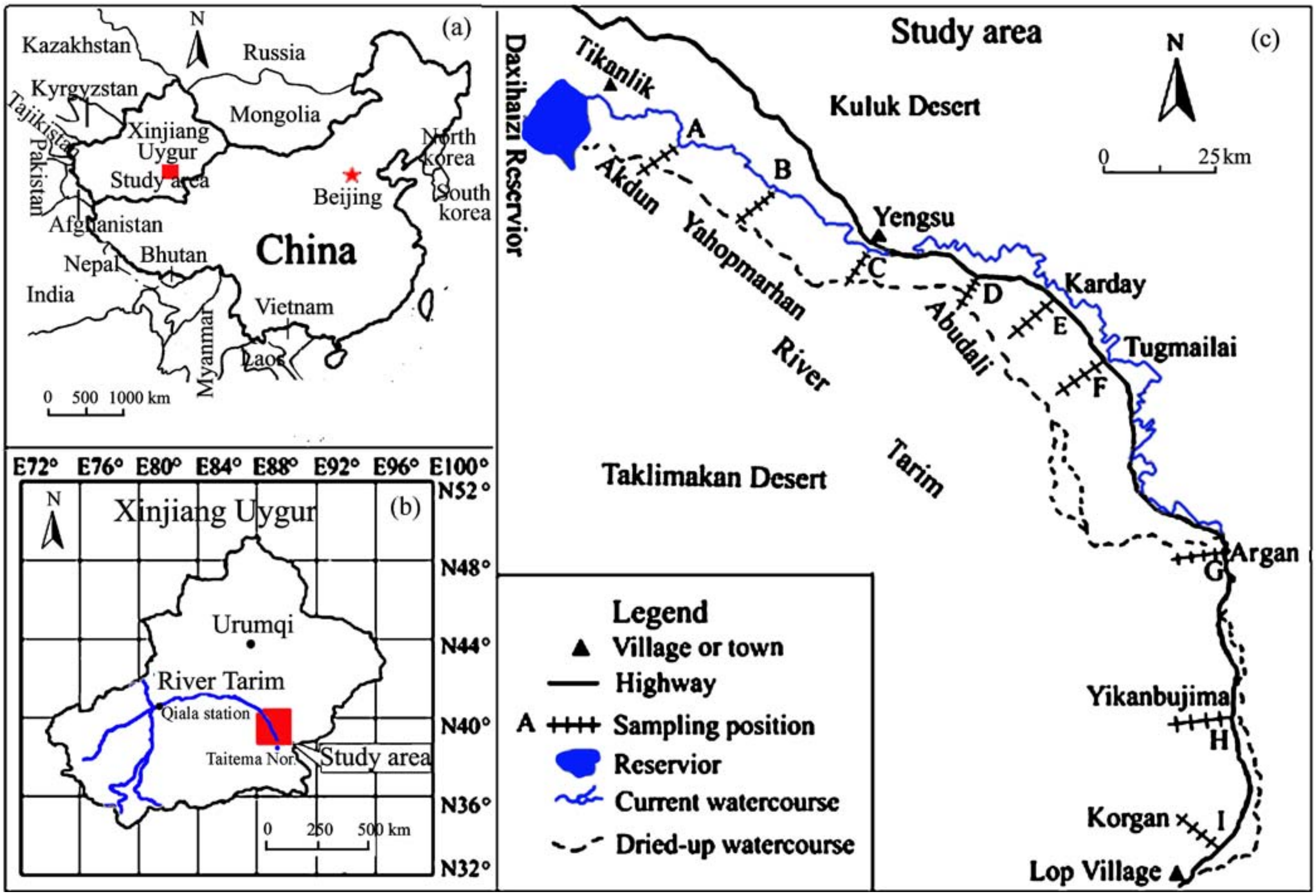

Fig. 1 **a**–**b** Location of the study area in Xinjiang Uygur region, China. **c** Monitoring cross-sections *A*–*I* within the study area

Study area and monitoring

Study area

Tarim River basin is the largest continental river basin in China (Fig. 1). With an area of 1.02×10^6 km^2, there are 114 rivers in nine major river systems, namely, Aksu, Hetan, Yarkand, Qarqan, Keriya, Dina, Kaxgar, Kaidu-Konqi and Tarim rivers. The mean annual runoff of surface water is 3.98×10^{10} m^3, fed by water from glaciers and snowmelts as well as rainfall in the mountains. Tarim

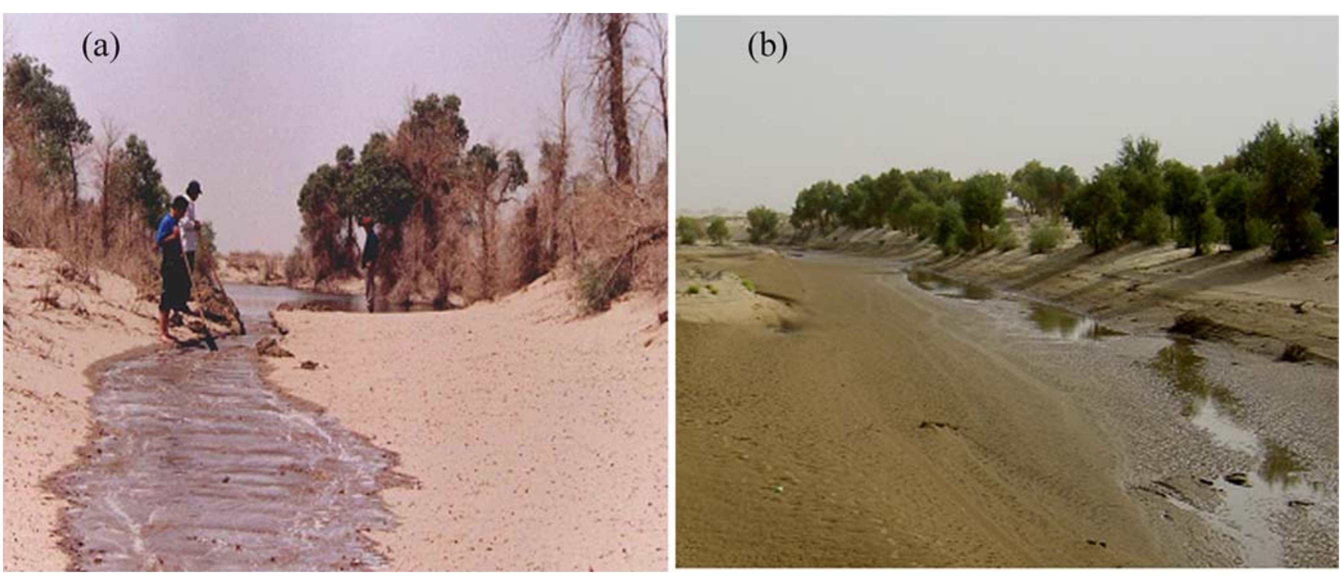

Fig. 2 Vegetation conditions **a** before water delivery and **b** after water delivery in the lower reaches of Tarim River

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Table 1 Eight ecological water deliveries to the lower reaches of Tarim River

Delivery	Starting date (day/month/year)	Ending date (day/month/year)	Duration (days)	Water amount (10^4 m^3)
First	14/5/2000	13/7/2000	61	9,883
Second	3/11/2000	14/2/2001	104	22,000
Third	1/4/2001	6/7/2001	97	18,400
	12/9/2001	17/11/2001	67	19,700
Fourth	20/7/2002	10/11/2002	110	29,300
Fifth	3/3/2003	11/7/2003	131	25,000
	12/9/2003	7/11/2003	56	9,000
Sixth	22/4/2004	25/6/2004	62	12,000
	27/8/2004	7/11/2004	70	23,000
Seventh	7/5/2005	7/6/2005	30	5,200
	30/8/2005	31/10/2005	61	22,800
Eighth	25/9/2006	21/11/2006	56	23,300

River basin represents a closed catchment hydrologically, and it is a unique freshwater ecosystem located near Taklimakan Desert, also the largest desert in China. Among the three headstreams flowing to Tarim River, Aksu River is the principal source, occupying 73.2% of the total flow; Hetan River and Yarkand River take up 23.2 and 3.6%, respectively (Chen et al. 2003a, b).

The study area is located between Daxihaizi Reservoir and Taitema Nor (lake) in the lower reaches of Tarim River (39°38′—41°45′N, 85°42′—89°17′E). The channel stretches to the southeast on alluvial fans between Taklimakan and Kuluk deserts. The ground surface is remarkably flat, with a descending elevation from north to south. Water seeps from streams into the alluvial fans to recharge the phreatic aquifer. The region is an extremely arid zone. The annual precipitation varies in the range 17–42 mm, and the total annual potential evaporation is 2,500–3,000 mm. Strong winds blow frequently in the region.

Riverbank vegetation provides a natural defense against the wind by obstructing sand movement. The famous Green Corridor plays an important role in keeping National Highway No. 218 free of obstructions. The flora of the region consists of 14 families, 24 genera, and about 40 species of vascular plants. The major plant species include *Populus euphratica oliv., Tamarix ramosissima*, *T. hispida*, *Lycium ruthenicum*, *Phragmites communis*, *Alhagi sparsifolia*, *Apocynum venetum*, *Karelinia caspica* and *Glycyrrhiza inflata*. The natural vegetation such as the shrub-grass vegetation, is dominated by *T. chinensis*, *Halimodendron halodendron*, *Phragmites communis*, *Apocynum venetum*, etc., and the forest is dominated by *Populus euphratica*. Both shrub-grass and forest rely on groundwater for their survival and growth, and have been seriously degenerated. The sand dunes of the sand region between the forests have become unstable.

The construction of the Daxihaizi Reservoir in 1972 reduced the water flow into Tarim River and dried up a length of 321 km in its lower reaches. The water table had dropped to 8–12 m due to lack of recharge by surface water for 30 years. Starting from year 2000, diversion of water from Konqi River has been implemented and altogether eight intermittent water deliveries had been realized by the end of 2007. The water table was raised significantly and riparian vegetation has improved. Figure 2 shows the difference in vegetation before and after the water diversion.

Monitoring

The study area focuses on the riverway from Daxihaizi Reservoir to Lop village (Taitema Nor) in the lower reaches of Tarim River. There was no flow in this section of the river after the completion of the Daxihaizi Reservoir in 1972. Before the water releases were implemented in 2000, nine monitoring cross-sections had been estab-

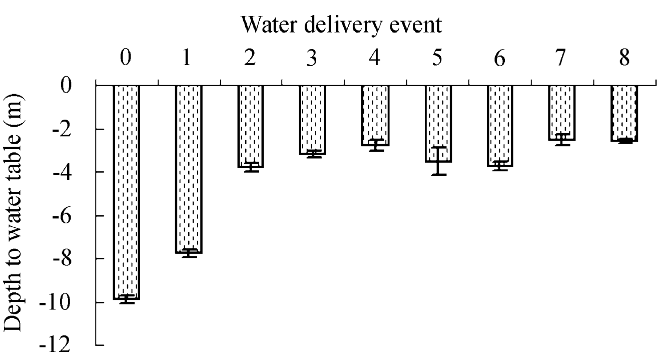

Fig. 3 Change of the water table during the processes of water delivery at 150 m away from riverway in section C. *Error bars* indicate one standard deviation from the mean. The same applies to the remaining figures where error bars are used

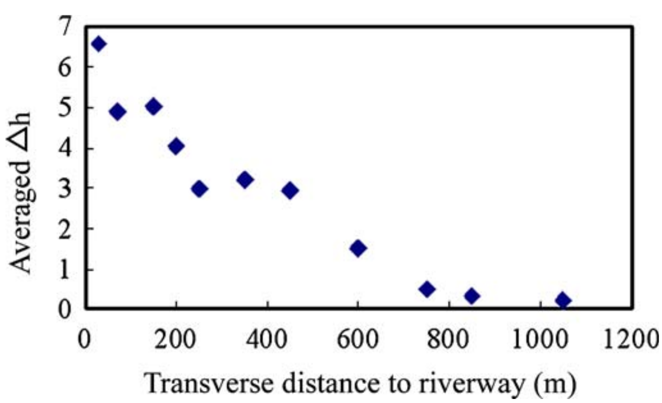

Fig. 4 Transverse change process of the water table in section C of the lower reaches in Tarim River. Δh is the difference between the original groundwater level and that after the 4[th] water delivery. Averaged Δh is the mean value of all nine sections

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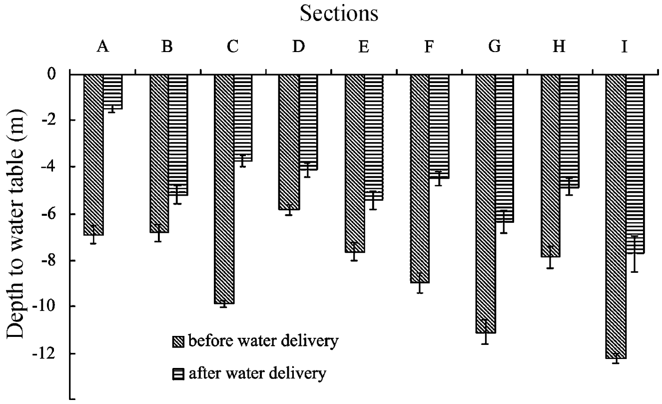

Fig. 5 Longitudinal profile of the change in water-table depth, responding to the water deliveries

lished, namely, Akdun (A), Yahopumarhan (B), Yengsu (C), Abudali (D), Karday (E), Tugmailai (F), Argan (G), Yikanbujima (H), and Kargan (I) sections. The interval between two neighboring sections of the first six sections is about 20 km, and the interval for the last three sections is about 45 km. Along each section, monitoring wells of 8–17 m depth were dug at intervals of 100–200 m to monitor changes of groundwater level. In total, 40 monitoring wells were set up. Measurements have been carried out three times a month during the water releases and once a month during the water-release intervals.

Based on the distribution of natural vegetation, five representative cross-sections (sections A, C, D, E and G) were selected for this study. Twenty-eight 50×50 m plant survey plots were sampled along the cross-sections. Within each plot, four 25×25 m sub-plots were sampled to record characteristics of trees and shrubs such as number of species, coverage, diameter at breast height, basic diameter, height and width of canopy. Four herbaceous surveys were undertaken in each plot to investigate the number of species, coverage, height, and frequency in July of each year when there was maximum biomass. Elevation, latitude, and longitude of each survey plot were recorded using a global positioning system (GPS) while

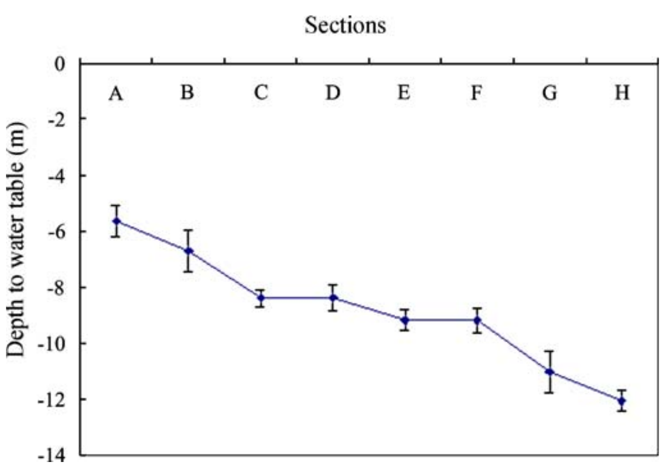

Fig. 6 Distribution of water table depth at the monitoring sections before the first water delivery in year 2000

the depth of groundwater and soil-water content were also recorded.

Based on the distribution of natural plants, different plants were chosen as the target species in each cross-section for the vegetation type in that area. *Phragmites communis* was chosen as the research target at the Akdun (A) cross-section. The height, length, width, and weight of 50 leaves of *Phragmites communis* were recorded. *Populus euphratica,* the dominant species of the desert riparian forests in the lower reaches of Tarim River, was chosen as the research target in the cross-sections C, D, E, and G. Some representative *Populus euphratica* trees were also selected near the monitoring wells. For each selected *Populus euphratica*, the length of 50 newly grown branches were recorded along with the number, length, width, and weight of 50 leaves of the newest branches at a height of 2–2.5 m.

The following indices were calculated to evaluate the changes in the species diversity: the Margale index (Margalef 1958), which reflects the richness of species; the Simpson index (Simpson 1949); the McIntosh index (McIntosh 1967), which represent the evenness of species.

The indices are calculated using the following formula:

$$\text{Margalef index}: \; D_{M\,\arg alef} = (S-1)/\ln N$$

$$\text{McIntosh index}: \; E = 1 - \sum_{i=1}^{S} \frac{N_i(N_i-1)}{N(N-1)}$$

$$\text{Simpson index}: D_{Simpson} = \sum_{i=1}^{S} \left(\frac{Ni}{N}\right)^2$$

where, N_i is the number of individuals of species i; N is the total number of individuals in each sampling plot; S is the number of species sampled in a plot.

$$\text{Calculation of density}: \mathrm{D_{en}} = \mathrm{N}/A,$$

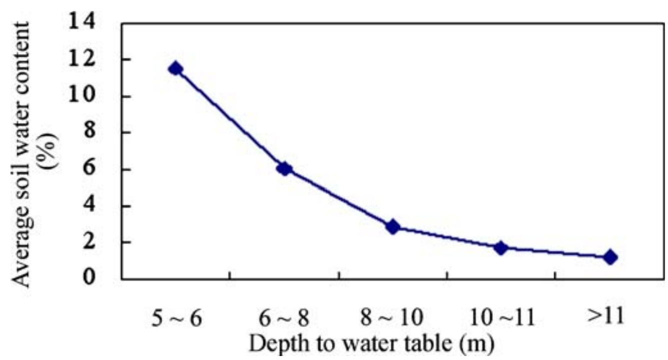

Fig. 7 Water table depth and soil water content (weight %) before water delivery of the lower reaches of Tarim River. Soil water content was a mean value for the soil depth range of 0–1.70 m

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Table 2 Characteristics of vegetation related to the depth of groundwater at each monitoring section before water releases in the lower reaches of Tarim River. *mbs* meters below surface

Section	Vegetation coverage (%)	Vegetation density (individuals/m^2)	Vegetation abundance (Margalef index)	Species number(per plot 50×50 m)	Mean water table depth (mbs)
A	80.86	0.34	1.48	11	5.5
C	27.62	0.12	1.40	9	8.34
D	23.18	0.09	1.29	8	8.41
E	21.86	0.05	1.24	8	9.16
G	9.72	0.01	0.87	4	11.1

where, *N* is the number of plants, *A* is the area of the plot (50×50 m in this study).

Coverage is obtained by direct measurements: the ratio of the vertical shadow against the area of plot. Richness is a measure of plant diversity. Evenness is a measure of vegetation density variation in an area being analyzed.

Results and analysis

Response of the water table to the water diversion

Water delivery for ecological restoration in the lower reaches of the Tarim River is targeted at the natural river course. From 2000 to 2006, eight intermittent water deliveries were implemented (Table 1), and the water table rose remarkably (Hou et al. 2007a, b). For example, at the upper section C, the groundwater level rose from 9.87 m depth before water delivery to 7.74 m after the first water delivery, 3.79 m after the second, and 3.16 m after the third water deliveries, representing a 21.6, 51.03 and 19.93% rise, respectively (Fig. 3). Detailed analysis shows that during the water deliveries, response of the water table to water deliveries diminished as the groundwater level rose up to 3 m depth in upper sections B and C, 5 m in middle sections D, E and F, and 7 m in the lower sections G, H and I.

The transverse response scope of the water table was gradually enlarged along both sides of the channel of conveyances, i.e., from 450 m in width after the first water delivery to 1,050 m after the fourth water delivery each side of the channel, but the degree of response in the water table was reduced with the increase of the transverse distance away from the riverway of water delivery (Fig. 4).

The monitoring results of the nine sections along the river channel show that, longitudinally, the response of the shallow water table to the water deliveries was different from the upper sections to the lower sections. The rising amplitude of the water table was bigger in the upper sections than in the lower sections. In section A, for example, the amplitude was 74.29% of the original depth to the water table, while in section F, it was 44.44% and in section I, it was 30.07%. In addition to this, the uprising amplitude of the water table decreased with the increasing distance from the Daxihaizi Reservoir, the source of water delivery (Fig. 5).

Relationship between the water-table depth and soil-moisture content

The long-time absence of water flow in the river has led to a significant fall of the water table along the river channel with a progressive downward trend towards the upper stream. From the upper to the lower stream in the study area, depth of the water table fell from -5.5 m in upper section A to -9.16 m in middle section E and down to -12.07 m in lower section G (Fig. 6). Soil-water content was strongly influenced by the depth of the water table and it decreased gradually with increasing depth of the water table. The average soil water content for the soil depth range of 0–1.70 m was 11.5% when depth to groundwater was 5–6 m, while it was only 1.69% for a 10–11 m groundwater depth (Fig. 7).

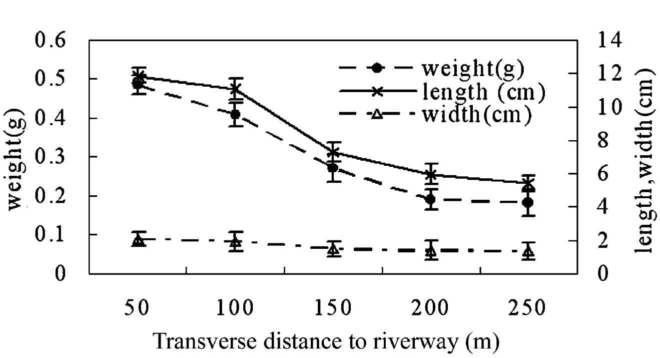

Fig. 8 Transverse profile of characteristics of *Phragmites communis* leaves at the Akdun (A) section

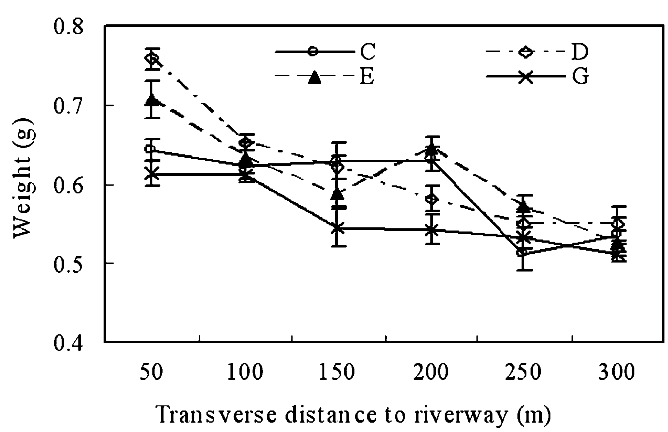

Fig. 9 Transverse profile of average weight of *Populus euphratica* leaves at different sections

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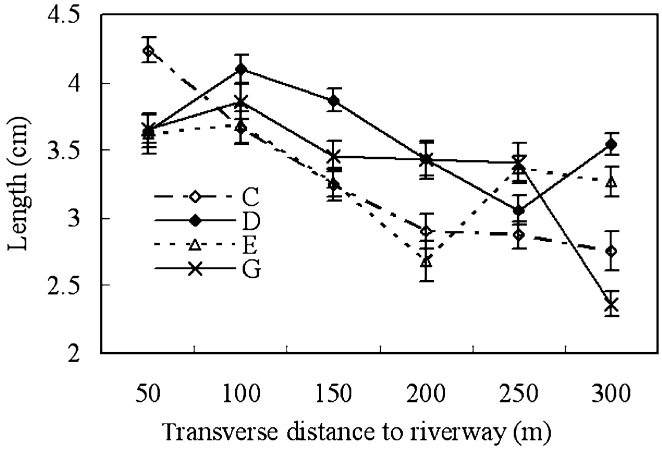

Fig. 10 Leaf length of *Populus euphratica* at different sections

Relationship between vegetation and the water-table depth before water delivery

Characteristics such as composition, distribution, and growth of riparian vegetation are closely related to the condition of groundwater. Before the water deliveries, with increasing groundwater depth from section C to Taitema Nor, plant communities changed from three layers (tree, shrub and herb) to those with only one layer (shrub). In sections C and D, as well as the western part of section E, trees (*Populus euphratica*), shrubs (*T. ramosissima*, *T. hispida, Nitraria sibirica, H. halodendron*) and herbs (*G. inflata, Poacynum hendersonii, Alhagi sparsifolia, Phragmites communis*) occurred in the communities, among which *Populus euphratica* and *Tamarix spp*. were the dominant species. In the eastern part of sections E, F, G and H, plant communities consisted of trees (*Phragmites communis*) and shrubs (*Tamarix spp., N. sibirica*) with a few herbaceous species (*Alhagi sparsifolia*). In the lower part of section I, the plant community only consisted of shrubs with very poor growth. Some species with a high drought-tolerance capacity existed when the depth of groundwater was greater. The coverage, density, and abundance of the plant communities decreased with the increase in groundwater depth (Table 2). The areas of decreased vegetation coverage and density were larger than that of reduced species abundance. Species diversity decreased with increased no flow time and also with groundwater depth. From section C to section H, the Simpson diversity index decreased from 0.70 to 0.26, the McIntosh index from 0.48 to 0.17, and the Margalef index from 1.40 to 0.87. It is clear that there is a close relationship between natural vegetation and water-table depth in the study area.

Response of vegetation to the water-table changes after the water deliveries

Natural vegetation in the study area is mainly comprised of *Populus euphratica* and *Tamarix spp*., whose survival depends on groundwater and soil water. Therefore, the change in depth of shallow groundwater has a direct influence on the development of natural vegetation. After water deliveries, the change of natural vegetation was closely related to the rising water table along the longitudinal and transverse directions. Some plants, such as *G. inflata, Alhagi sparsifolia, Apocynum venetum, Phragmites communis, Salosola sp., Scorzonera sp.*, and *K. caspica*, appeared again in profusion in the study area. Some drought-tolerant trees and shrubs were restored together, when the water table reached its common optimal depth (4–6 m).

Since different plants require different optimal groundwater levels, the sensitivities of plants to the change of groundwater depth are different. Among some herbaceous plants, it was found that the leaf characteristics of *Phragmites communis* are highly sensitive to groundwater change. In the transverse direction, the weight, length, and width of the leaves of *Phragmites communis* at the first sample location, 50 meters from river, are the biggest and they become smaller as distance from the river channel increases (Fig. 8). This shows that the response is most sensitive at 100–150 m from the river and the growth indices of *Phragmites communis* fall significantly beyond this range.

The measurement of the newly generated branches of *Populus euphratica* and the number, length, width, and weight of 50 leaves of those newly generated branches shows that the growth of *Populus euphratica* has an active response to the rise in groundwater in all locations. In the transverse direction, average leaf weight of *Populus euphratica* was examined at section C, D, E, and G, which shows that average weights of all 50 leaves fall with increasing distance from the river channel. Average leaf weights of *Populus euphratica* changes significantly from 50 to 200 m, but the changes from 250 to 300 m are small. This indicates that the transverse response range is from 200 to 250 m (Fig. 9).

Length of the leaves of *Populus euphratica* shows obvious variations with the distance from the river channel. Leaf length near the river was larger than that far away from the river. Difference of average leaf lengths at different sample locations indicated that the response range was about 100–200 m from the river course (Fig. 10).

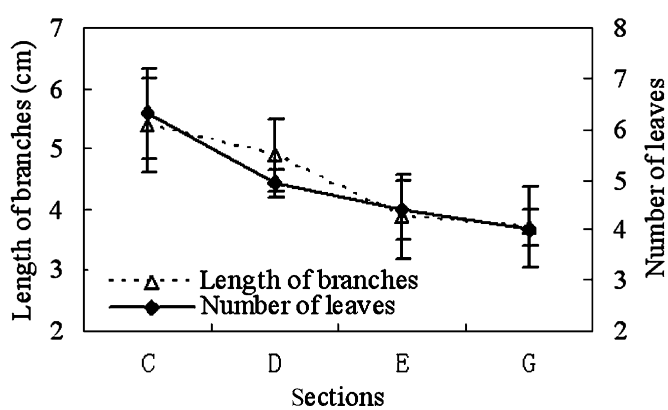

Fig. 11 The average length of newly generated branches and number of leaves in different sections

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Measurements of new branches of *Populus euphratica* from the sections C to G along the river indicate that the lengths of new branches vary significantly, caused by water-table depth at different sections. New branches of *Populus euphratica* in the upper sections are longer than those of the lower sections. Average lengths of new branches in sections C, D, E, and G are 5.39, 4.89, 3.89, and 3.7 cm, respectively. Using the new branches of section G in the lower reaches as a reference; those of the other three sections increased 45.7, 32.2, and 5.1%, respectively (Fig. 11).

Similarly, the number of leaves on new branches of *Populus euphratica* at different sections shows obvious variations between the sections and the plant survey plots. More leaves were found at the upper sections than in lower sections. Average numbers of leaves on branches are 6.31, 4.91, 4.39, and 4.02 for sections C, D, E and G, respectively. Using the average number of leaves of section G as a reference, those of the other three sections increased 57, 22.2, and 9.2%, respectively. This change of leaf number is more significant than that of new branch length.

Discussion and conclusions

In the lower reaches of the Tarim River, riparian vegetation strongly depends on groundwater. Reduction in stream water induced a falling water table, and thereby, soil water content, which had led to degradated riparian vegetation and decreased biodiversity. The water deliveries to the lower reaches of the Tarim River have resulted in a significant rise in the water table, which has led to good growth of some drought-tolerant trees and shrubs. The response of *Populus euphratica* became more remarkable with increased water releases. This means that water delivery can play an important role in restoration of riparian vegetation in this area.

Due to the long-term water shortage and falling water table before the water releases, the *Populus euphratica* forest was dying. The river water releases have led to a rise of the water table and partial restoration of natural vegetation though it could not stimulate the growth of *Populus euphratica* and *Tamarix spp*. More water releases are needed in the future to improve the ecological benefits. Seeding time and other factors may be considered in future operations in order to accelerate plant generation. Since optimal water table depth varies for different plants, the sensitivities of plants to change of groundwater depth are different. Some drought-tolerant trees and shrubs were restored together when a rising water table reached their common optimal depth.

According to statistics, the sensitive response distance of *Phragmites communis* is about 100–150 m from the riverway; while that of *Populus euphratica* is about 200–250 m. These two are dominant species of desert riparian forests in lower reaches of the Tarim River. From the upper and lower sections, the length of new branches has increased by 45.7, 32.2, and 5.1% for sections Yengsu(C), Karday(E) and Aragan(G), respectively; while the number of leaves on new branches has increased by 57, 22.2, and 9.2%, respectively.

From the upper to the lower area, analysis of different degrees of ecological process response showed that the longer the duration of water releases, the greater the groundwater would rise, and the larger the range of vegetation was influenced. It was found that the duration and volume of water delivery was closely related to restoration of vegetation in lower reaches of the Tarim River. Differences in the response distances of *Populus euphratica* and *Phragmites communis* indicated that the optimal groundwater level for these two plants was different.

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