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Degradation of *Populus euphratica* community in the lower reaches of the Tarim River, Xinjiang, China

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Abstract: To investigate the relationships between the degradation of plant community and groundwater level in the lower reaches of the Tarim River, nine monitored sections were set along the main stream, where there had been no runoff for nearly 30 years. The characteristics of plant communities were analyzed. It was found that the coverage of trees gradually decreased along the groundwater depth gradient, while the coverage of shrubs slightly increased rather than decreased at first and then gradually decreased, and the coverage of herbs steadily decreased at the beginning and then quickly decreased. The species diversity and species richness of both herbs and woody plants showed obvious degrading trends, while the variations in species evenness were slight. The degrading sequences of species were related to their physiological and ecological characteristics, especially their sensitivity to changes of groundwater table. The herbs with shallow roots first degenerated or disappeared when the groundwater table fell, and then did the deep-rooted herbs, and finally the trees and shrubs with strong tolerance to drought degenerated. The *Populus euphratica* communities showed typical degrading characteristics, namely the dominant species *Populus euphratica* remained its dominant status during the degradation. Overall, the existence of strongly tolerant-drought species was the obvious indication of plant species degradation; while simplification of community structure and the decrease of species richness were the obvious indication of plant community degradation.

Keywords: degradation; plant community; coverage; species diversity; Tarim River

Introduction

Riparian systems are aquatic-terrestrial ecotones with unique biotic, biophysical and landscape characteristics (Gregory, 1991; Naiman, 1997; Wiens, 2002) and are shaped by fluvial geomorphic processes. Riparian plant communities perform an important array of stream bank stabilization(Osborne, 1993; Chen, 2003a; Liu, 2003). Usually, spatial variation of plant communities in species composition and structure is determined primarily by flooding (Walker, 1986; Wang, 2000; Capon, 2005). Because the seed germination and seedling survival in riparian forests rely heavily on high flows and the gradual recession of flows, which allow the seeds or seedling roots to remain in contact with the alluvial water table. In addition, the growth of mature riparian trees is also governed by the stream-flow. So the plant species distributions within riparian zones can be regarded as the mirror of the hydrological conditions. Usually, hydrological conditions vary frequently influenced by either the intense human activities or the changing environmental factors. Meanwhile, the composition and structure of plant communities may respond to those changed conditions(Couteron, 2001; Rietkerk, 2002).

The Tarim River, which is also called "the water of life", lies in the southern Xinjiang Province. It runs from the west to the east of Xinjiang, going through the northern edge of the Taklimakan Desert. The main stream from the Xiaojake to Taitema Nor. is 1321 km long(Liu, 2000; Song, 2000). Its lower reaches start from the Qiala Reservior and end at the Taitema Nor. The riparian forests along both banks of the lower river are usually called "the green corridor" because of their functions in preventing desertification and protecting the national highway 218. However, the decline of riparian vegetation in the lower reaches in the last 30 years has been due, in part, to impoundments and diversions of surface water for human use in the upriver stream valley(Lei, 1994; Li, 2001; Wang, 1997; 2000; Fang, 2001; Sun, 1983). Such decline has been reflected by the loss of species and soil desertification(Hu, 1983; Liu, 2004, Chen, 2003a). The relationships between water and ecological and physiological characteristics of plants have been intensively studied (Huang, 1993; Chen, 2003; Zhang, 2003a; 2003b; Liu, 2004) but few studies were conducted on the interpretation of vegetation degradation, changes in succession of plant communities and the variations of species composition. In this paper, we attempted to elucidate dynamic of vegetation degradation of the lower river by analyzing (1) the sequences of species degradation and their ecological characteristic; (2) the changes of plants communities in structure and species composition; (3) the variation in species diversity along the lower river; and (4) the changes in coverage of different plant life-form groups. We also discussed the potential effects of human activities on the ecological changes.

1 Study area

The study area, the lower reaches of Tarim River, is located in the east of Tarim Basin and links the Taklimagan Desert and Kuluk Desert together(Liu, 2000). It belongs to the extremely arid zone with continental warm temperate climate. The total annual solar radiation varies from 5692 to 6360 MJ/m^2 with the cumulated sunlight from 2780 to 2980 h. The annual cumulated temperature($\geqslant 10$℃) varies from 4040℃ to 4300℃ with an average diurnal range of 13℃ to 17℃. The total annual precipitation ranges from 100 to 200 mm and the annual evaporation is more than 2000 mm(Liu, 2000). The typical floras include those plants from the Ancient Mediterranean, the Middle Asia and pan-tropical zone etc. The total vascular plants are classed as 14 families, 24 genera and 40 species (Liu, 1995). Of these, the dominant species include *Populus euphratica*, *Tamarix ramosissima*, *T. hispida*, *Lycium ruthenicum*, *Phragmites communis*, *Alhagi sparsifolia*, *Apocynum venetum*, *Karelinia*

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caspica, *Glycyrrhiza inflata*, and so on.

2 Methods

2.1 Data collection

In the study area, the nine sites(called nine monitored sections in the following text) were selected for sampling. We named respectively them Akdun (A), Yahepu (B), Yinsu (C), Abudali (D), Kardayi (E), Tugmailai (F), Alagan (G), Yiganbjima (H) and Kaogan (I) (The letters A—I symbolized the nine monitored sections). In the monitored sections, forty groundwater wells were drilled at the perpendicular angle to the stream way. We sampled 56 plots in the six monitored sections, 10 for woody plant stands(trees and shrubs) and 46 for herbs (Fig. 1). In each plot, a reasonable degree of homogeneity in topography was ensured. Each woody plant plot consisted of four quadrates of 25 m × 25 m for inventory of trees and shrubs and of four 5 m × 5 m for grass. Each grassland plot consisted of six quadrates of 5 m × 5 m (at Akdun monitored section). In each plot, all vascular species were identified. In the woody plant plots, trees(> 5 cm(DBH)) and shrubs(including seedlings < 5 cm(DBH)) were counted, and breadth of canopy(length and width) of both trees and shrubs, heights of shrubs and number of individuals were measured. Herbs in woody plant plots and in plots of grasslands were counted, and their heights and cover percentage were measured. In addition, some variables were measured or collected in each plot including main environmental factors: elevation, groundwater level, soil moisture, salinity of soil(i.e. salinity percentage) and soil nutrient(i.e. nitrogen percentage) and so on. The total of 17 vascular species were recorded in the 56 plots (Table 1). The data of runoff in the past fifty-year were obtained from the permanent hydrological stations along the river(Song, 2000)(Table 2). The survey of plant community was carried out, and the former study results on plant communities were collected from the relative literature.

Table 1 List of 17 main plant species in the lower reaches of the Tarim River

Code	Species	Code	Species
1	*Populus euphratica*	10	*Karelinia caspica*
2	*Tamarix ramosissima*	11	*Salsola* sp.
3	*T. hispida*	12	*Halostachys caspica*
4	*Lycium ruthenicum*	13	*Salsola ruthenica*
5	*Halimodendron halodendron*	14	*Hexinia polydichotoma*
6	*Phragmites communis*	15	*Scorzonera* sp.
7	*Alhagi sparsifolia*	16	*Taraxacum* sp.
8	*Glycyrrhiza inflata*	17	*Kochia prostrata*
9	*Apocynum venetum*		

Table 2 Water volume ($\times 10^6$ m^3) of different sections from the hydrological stations

Period	Qiala station			Tikanlik	Alagan	Luob Village
	Tarim River	Peacock River	Total			
1951—1960	1353	0	1353	900—800	Water	500—400
1961—1970	1138	0	1138	288	Little water	23
1971—1980	669	100	769	47	No water	No water
1981—1990	392	201	593	36	No water	No water
1991—2000	284	226	551	6	No water	No water
Average	698	106	804	183	No water 25 year	No water 27 year

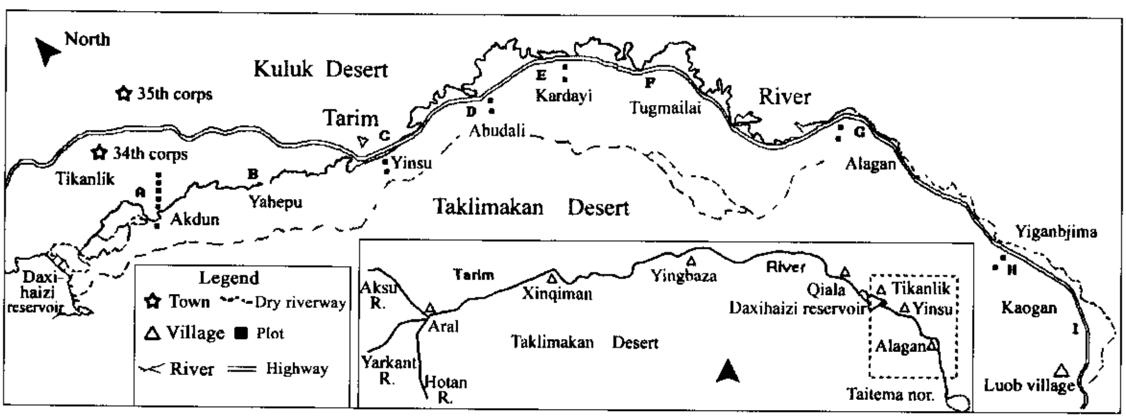

Fig.1 Nine monitored sections, 10 plots for woody plant(from Yinsu to Yiganbjima sections) and 6 plots for herbs(at Akdun section). The sections names was replaced by the alphabet

2.2 Data analyses

The temporal dynamics of vegetation degradation was obtained by analysis on spatial changes in vegetation(Peng, 1994). Firstly, the spatial, gradient changes in environmental factors need to be analyzed. Then, the vegetation types at different monitored sections need to be analyzed. Finally, the feasibility study on the processes of vegetation degradation was confirmed. It should be pointed out that the characteristics of plant community at Akdun monitored section were not analyzed in the paper due to the intense disturbance from human activity.

All quadrates within each plot were aggregated. Species diversity were estimated by the following three indices (Whittaker, 1972; Magurran, 1988; Ma, 1994): (1) Species richness S represented by the number of species recorded in each section; (2) Shannon-wiener's index of diversity (Shannon, 1949) $H = -\sum P_i \log P_i$, (3) Pielou's evenness index (Pielou, 1977.) $E = (-\sum P_i \log P_i)/\log S$, where $P_i = N_i/N$, N_i is the individuals of species i, N is the total individuals of all species present, and S is the number of vascular species. Dissimilarity indices (Beta-diversity) were estimated with Cody index(Magurran, 1988) $\beta_{ws} = [g(H) + l(H)]/2a$, where a is the average species richness in the plant community, $g(H)$ is the number of appearing species, and $I(H)$ is the number of disappearing species. Plots from woody plant communities and herbs were separately ranked to show the variations in those indices along the different monitored sections from Yinsu to Yiganbjima.

Species importance value (IV = (relative height + relative cover + relative density)/3) for shrubs and grass, the value(IV = (relative cover + relative density + relative dominance)/3) for trees and species coverage (sum of projection area (length × width of breadth)/2500) were calculated. Data were subjected to Detrended Correspondence Analysis(DCA)(Braak, 1991) for vegetation ordination with environmental variables. The correlative coefficients between environmental variables and the first two axes of DCA(Table 3) indicated that the first axis represented a main ecological gradient. Along the first axis from the left to the right, the dynamic of species degradation were analyzed.

Table 3 Correlations between environmental factors and axes

Environmental factors	X-axis	Y-axis
Groundwater table	0.5502	-0.1640
Salt capacity of soil	-0.0908	-0.1877
Soil moisture	-0.4415	0.0611
Altitude	-0.4420	-0.1466
Soil pH	-0.0924	0.2485
Soil nutrient	0.2373	-0.1149

The degrading succession of plant communities was inferred according to the plot data and literature. The literature records from the earlier studies(Hu, 1983; Sun, 1983; Liang, 1990; Huang, 1993; Fang, 2001) showed that the lower reaches of the Tarim River had diverted its watercourse five times in history. The fourth diversion resulted in the Taitema Lake as the end of the river. The fifth diversion in 1970 cut off the watercourse and ended the river to Daxihaizi Reservoir. Therefore, the vegetation began to degrade was after the fifth watercourse diversion. At that time, the type of plant community was *Populus euphratica* forest, which was the main community type on the north of Yiganbjima section. Some scholar emphasized the importance of standardized sampling in ensuring the objectivity of observed pattern(Lomolino, 2001). So, all the comparisons were among the plots with the same plot size.

3 Results

3.1 Disturbance and environmental gradient

Riparian ecosystem was sensitive to the changes in stream-flows. In the lower reaches of the Tarim River, the decrease of the stream flows resulted from both the anthropogenic and natural disturbance. The impoundments and diversions of surface water for human use in the upper and middle stream valley during the last 50 years greatly contributed to the water shortage of the lower stream valley, and brought the watercourse from Daxihaizi Reservoir to Taitema Nor. on dry since 1972(Table 2). In addition, inter-annual fluctuations of stream-flow were another reason caused water resource shortage severely in the study region (Fig.2).

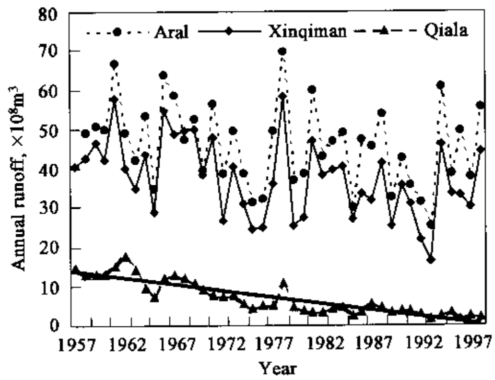

Fig.2 Annual changes in runoff at three hydrological station: Aral(at upper river), Xinqiman(at middle river) and Qiala(at lower river)

Because only a little precipitation was supplied in the lower reaches of Tarim River every year, the lack of permanent surface water must lead to groundwater level dropping gradually and declining of eco-environmental conditions. As a result, the groundwater depths along the lower river, from the Akdun to Yiganbjima monitored section, showed a gradient, spatial change(Fig.3a) and correspondingly the other environmental variables also did (Fig.3b). Such changes of groundwater in space were consistent with that of plant community structure and species composition(Fig.4). For example, both vegetation coverage and species richness gradually decreased(Fig.4b), while the proportion of woody species increased(Fig.4a).

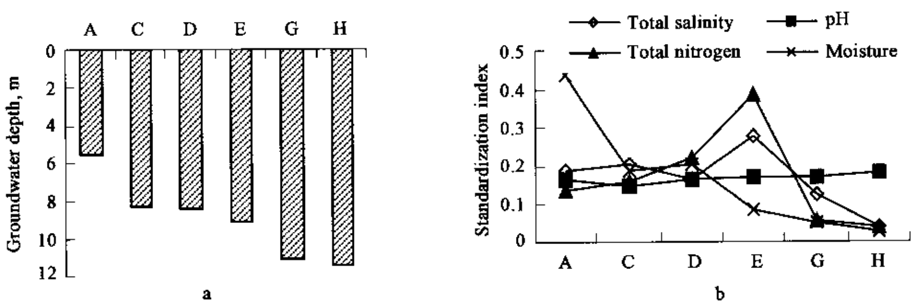

Fig.3 The distribution of groundwater level and other environmental factors

Among the nine monitored sections, the vegetation type at Akdun section was different from those at the other sections because of its nearest to Daxihaizi Reservoir. While the same vegetation types were in those sections from Yinsu to Yiganbjima, and the proportion of woody plant increased with increasing groundwater depth. Thus, the obviously spatial

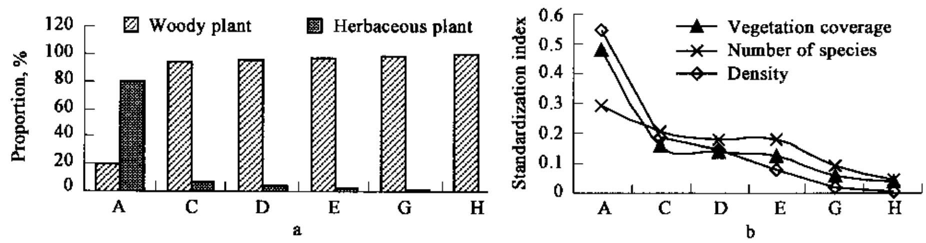

Fig.4 Vegetation patterns at different monitoring sections

changes in environmental gradient along the lower river, especially from Yinsu to Yiganbjiman section, provided the feasible ways to characterize the spatial and temporal changes in vegetation degradation.

3.2 Species diversity

Although the species richness of both herb and woody plants declined along with groundwater depth changes, while the species richness of herbaceous plants was lower than that of woody plants. Moreover, the herbs disappeared at the Yiganbjima section, thus the total species richness index was equivalent to the index of woody plants(Fig.5).

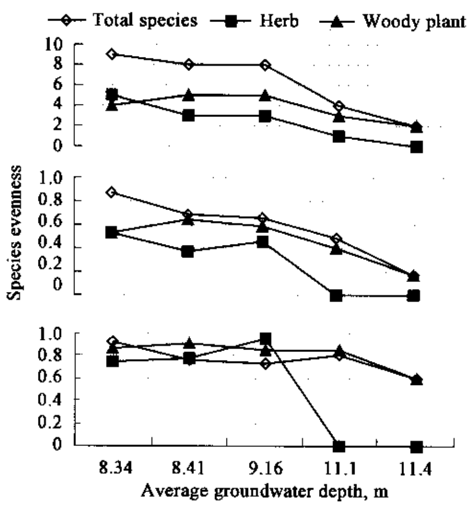

Fig.5 Herbs, woody plant and total species respectively ranked to show the variations of species richness, diversity and evenness indices from Yinsu to Yiganbjima section

The spatial trends of species diversity were similar to that of species richness. For all the study sections, the species diversity indices of herbs were lower than those of woody plants. Especially at the Alagan section, the species diversity index of herbs was zero. While the species diversity of woody plants showed a slightly increasing, then decreasing trend. The degrading trend was different from that of herb.

The variations in species evenness with the groundwater depth were not as obvious as the variations in species richness and diversity. The habitats in the study area were adverse to vegetation growth, which resulted in plants sparse, and the species evenness of plant communities was not greatly different from one section to another. While at the Yiganbjima section(groundwater 11.4 m depth), there were only two species (*Populus euphratica* and *Tamarix* spp.), herbaceous plant almost died out, so species evenness was lower than the other sections and the herbaceous plant evenness had become zero.

Moreover, it was proved that the Beta-diversity of plant communities linearly declined from Yinsu to Yiganbjima(Fig. 6), which suggested that the decline in species diversity had close relationship with groundwater depth. The species composition of plant community greatly varied, and influence the environmental gradient in the area. Whereas, the species diversity index for the woody plants was dissimilar to that for the plant community. It showed obvious single peak curve along the groundwater level gradient, and could be fitted well with a quadratic polynomial regression model.

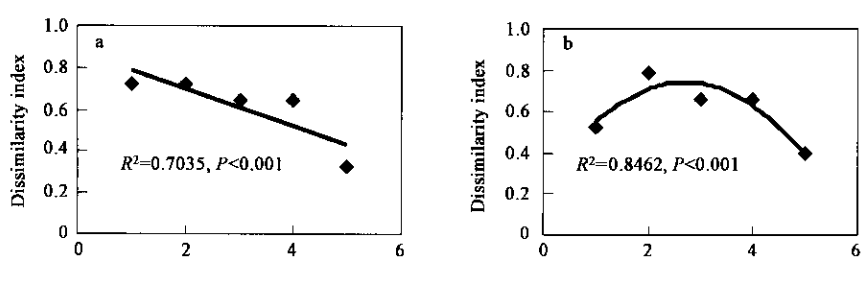

Fig.6 Dissimilarity(β-diversity) between pairs of total species(a) and woody plant(b)

3.3 Ordination

Correlative coefficients of environmental variables to the first two axes of DCA(Table 3) indicated that the first axis (axis X) with an eigenvalue of 0.9489 represented a main ecological gradient. Furthermore, the first axis was determined by groundwater level, soil moisture and altitude. Ultimately, the first axis referred to a groundwater gradient. The second axis(axis Y) was determined by soil pH. Along the first axis from the left to the right, 17 species showed different sensitivities to decreasing groundwater level.

The 17 species aggregated according to the DCA ordination (Fig. 7). Three groups were identified, each having explicit ecological implication. In the group one(Ⅰ), most species need humid environment, thus their root systems were not strong. In the group two(Ⅱ), except for a few herbs with deep root systems, most were shrubs or semi-shrubs enduring drought and salinity. *Populus euphratica* and *Tamarix* spp. were in the group three(Ⅲ).

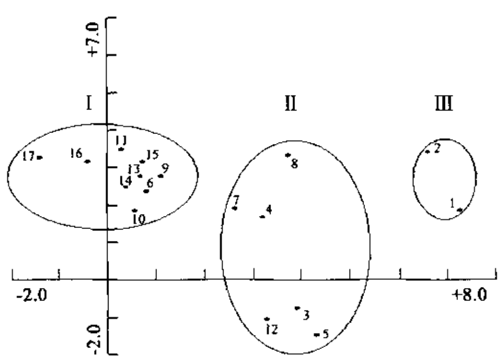

Fig.7 DCA analysis for the species in the lower reaches of Tarim River

3.4 Plant communities and species composition

As environmental conditions changed, plant communities would also vary in species composition and community structure. From Yinsu to Yiganbjima monitored sections, the *Populus euphratica* community was the main community type. Although the community types were the same, the dissimilarity coefficient of plant community between two sections had great differences (Table 4). The community structure, species density and species composition were different under the conditions of different groundwater depths (Fig.8). Namely, the lower the groundwater level was, the lower the species density was. The important value of some species in the plant community increased due to the disappearance of other species. For instance, the important value of *Populus euphratica* increased with groundwater level falling owing to its strong root system. When the species with shallow root could not survive and died out because of the groundwater was too deep for them to get, the important value of *Populus euphratica* enhanced relatively.

Table 4 Dissimilarity coefficient between plant communities among the five sections

Section name (Groundwater m)	Yinsu (8.34 m)	Abudali (8.41 m)	Kardayi (9.16 m)	Alagan (11.1 m)	Yiganbjima (11.4 m)
Yinsu(8.34 m)		0.15	0.23	0.32	0.54
Abudali(8.41 m)	0.15		0.245	0.39	0.58
Kardayi(9.16 m)	0.23	0.24		0.41	0.61
Alagan(11.1 m)	0.32	0.39	0.41		0.53
Yiganbjima (11.4 m)	0.54	0.58	0.61	0.53	

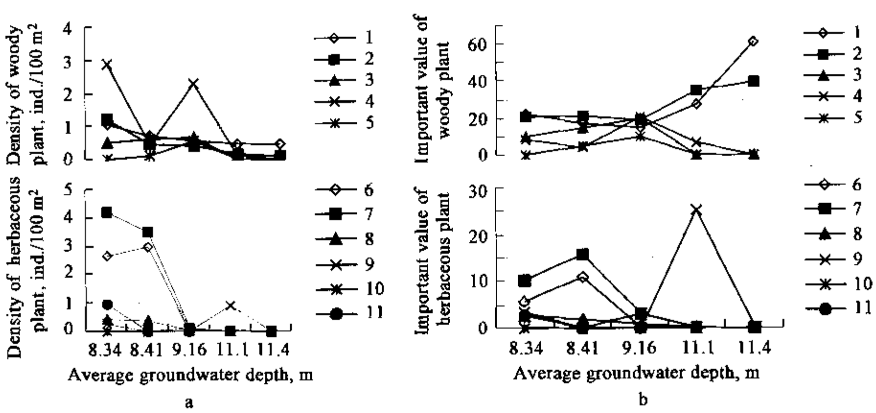

Fig.8 Changes of 11 plants in density(a) and important value(b) from Yinsu to Yiganbjima section

At the same time, the vertical structure of plant community with primary three layers(tree, shrub and herb) would also change because of some species disappeared. As shown in Fig.6b, when groundwater depth was 11.4 m, only *Populus euphratica* and *Tamarix* sppp. survived. So the three layers structure became two-layer structure.

4 Discussion

4.1 Disturbance, degradation and groundwater

Numerous studies have demonstrated the disturbances through varying the water supply to realize their control over vegetation patterns and dynamics in arid and semiarid zones (Lei, 1994; Li, 2001; Glenn, 2002; Chen, 2003a). In the Tarim River, water is the most important environmental factor, directly affecting the environmental conditions when it is inadequate (Zhang, 2003). Among all the disturbances resulting in water lack of the lower reaches of the Tarim River, natural disturbance (such as runoff change) and human activities(such as building Daxihaizi Reservoir) were the most important ones. Such disturbances influenced species distributions and abundances for almost 50 years and caused vegetation degradation. However, no quantitative assessment of the disturbances was done, only descriptions and effects of such disturbances were given based on actual observations. But the dynamic of vegetation degradation as indicators of the disturbance could be analyzed along environmental gradients.

Because the growth and survival of the riparian vegetation along the Tarim River were strongly dependent on stream-flow and the regular floods, many riparian plants in the area were phreatophytic, relying heavily on ground water and associated capillary fringe, thus relationships between riparian plants growth and stream-flow must also consider plants access to ground water (Stromberg, 1990; Chen, 2003b). So, spatial characteristics of plant distribution were closely related to groundwater level.

4.2 Species and degradation

Plant species usually posses attributes which enable either tolerance of environmental changes, through physiological or morphological traits (Blom, 1990; Blom, 1996). Drought tolerance is a species-specific response (Gulmon, 1992; Espigares, 1993), and it can therefore be expected that different species have different ecological and physiological characteristics to adapt degrading environment. DCA analysis in the paper showed a clear species-specific response to degrading environment.

Along the first axis of the DCA ordination shown in Fig. 7, we could clearly see the degenerating trend of species. As the groundwater level decreased, plant species also degenerated and disappeared. Some grass such as *Salsola* sp., *Scorzonera* sp. and *Taraxacum* sp. first degenerated or disappeared, and some seedlings of trees and shrubs were also difficult to survive. Then some deep-rooted herbs disappeared, such as *Apocynum venetum* and *Glycyrrhiza inflata*; and some shrubs also did, such as *Lycium ruthenicum* and *Halimodendron halodendron*. Then *Populus euphratica* and *Tamarix* spp. became unable to regenerate, and finally even degenerated and disappeared.

In the study area, some grass such as *Hexinia polydichotoma*, *Scorzonera* sp., *Taraxacum* sp., *Salsola ruthenica* have similar ecological characteristics preferring wet habitat, mostly growing in deltas, lowlands of river ladders and other wet soil. *Apocynum venetum* and *Glycyrrhiza inflata* can endure drought and resist saline-alkali soil. *Alhagi sparsifolia* can endure salinity and prefers warm environment, and its underground biomass is as thirty times as the aboveground biomass(Xia, 1995). So its strong roots can penetrate into deep underground. Usually, when groundwater depth is 1—2 m, most herbs can grow well. However, if the depth is more than 4 m, only a few herbaceous plants with deep roots can survive(Song, 2000).

Populus euphratica is a kind of xero-mesophyte tree. It goes through the evolvement from a mesophyte ecotype to xerophyte ecotype during its growth in the area (Zhang, 1996). Both its stems and leaves have the characteristics of xerophytes with strong tolerance to dry and saline habitat. Its seedlings can send out from its roots. *Tamarix* spp. mainly exists in arid, saline-alkali regions and can resist drifting sands, presenting wider adaptability to environmental conditions (Guo, 1991). The mature *Tamarix* spp. can adapt to dry or saline habitat(Wu, 1980) even though there are a lot of salts accumulated in soil due to rising groundwater. In a word, *Populus euphratica* and *Tamarix* spp. can resist salinity well, endure drought and make full use of environmental resources due to their deep roots, thus their survival was determined by root depth of individuals.

4.3 Plant communities and degradation

Plant community type, as an important part of an ecosystem, usually denotes certain special ecosystem type (Kent, 1992). Species composition and community structure are not only the basic factors to indicate characteristics of plant community, but also the important factors to distinguish different types of plant community(Sun, 1993; Shi, 2002; Li, 1999). So, to analyze the characteristic of plant community was important and we could get the degrading characteristic of community according to spatial pattern of vegetation. Before vegetation degradation, there were three vertical layers, i.e. tree, shrub and grass layer in the *Populus euphratica* forests community. According to different groundwater depths (Fig. 9) and changes in the number of species and species density (Fig. 6), the process of degradation could be divided into three stages. During the first stage, most herbs under trees degenerated or disappeared and the plant community gradually evolved into the *Populus euphratica* + *Tamarix* spp. community associated with a few *Glycyrrhiza inflata*, *Alhagi sparsifolia* and *Apocynum venetum*, for example, at the present Kardayi section. As groundwater continuously fell down and the second stage of community degradation began, the plant community gradually evolved into *Populus euphratica* + *Tamarix* spp. associated with fewer *Apocynum venetum* or *Alhagi sparsifolia*, for example, at the present Alagan section. The third stage, severe degradation, was characterized by the near total loss of herb, the plant community would evolve into *Populus euphratica* + *Tamarix* spp., for example, at the Yiganbjima section. During the vegetation degradation, *Populus euphratica*, the dominant species, did not lose its dominant status in the community. Along with the further development of degrading succession, the species would only left *Populus euphratica* and *Tamarix* spp. in the community with drifting sands. In a word, the existence of strongly tolerant-drought species was the obvious indication of species degradation; while simplification of community structure and the decrease of species richness were the obvious indication of plant community degradation.

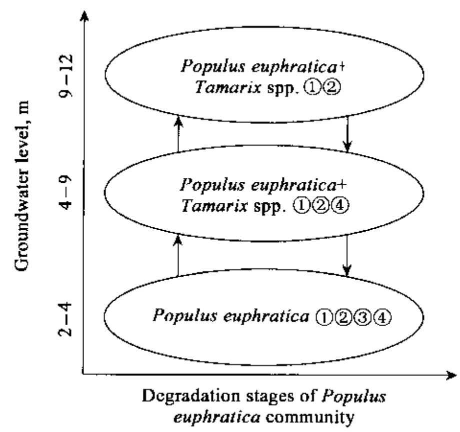

Fig.9 Degraded succession of *Populus euphratica* community
① tree layer; ② shrubs layer; ③ herbaceous plants with shallow roots; ④ herbaceous plants with deep roots

4.4 Diversity and degradation

Species diversity can be regarded as an index of ecological gradients and environmental quality(Alard, 1994; 2000). In the study area, species diversity is rather low (Huang, 1993; Guo, 1991; Liang, 1990) and spatial variation of species diversity was found to be consistent directly with change of groundwater depth(Fig.4). That is to say, species diversity was high in the environments that were provided with high groundwater level, where some herbs could remain in contact with the groundwater table. Conversely, diversity may be low in the environments that were provided with lower groundwater level, where vegetal roots were difficult to contact with groundwater especially herbaceous plant. Therefore the gradient change in environment condition caused the changes in species diversity in the area. But plant species evenness did not greatly vary.

Moreover, the diversity and richness indices of plants life-forms groups disclose significant differences along the gradient of groundwater depth. Namely, the species diversity of woody plants was higher than that of the herbs at the same monitored section. The best explain was because the woody plants and herbs represent different functional groups, they may have different strategies of resource utilization and different competitive and physiological abilities (Guo, 1991; Yang, 1997; Lyon, 2002; Liu, 2004) especially under the conditions of environment decline. In the paper, the vegetation degradation was demonstrated by changes in species diversity and species richness. That was species diversity and species richness of both herbs and woody plants that showed obvious degrading trends along the environmental gradient. At some extent, it might be a response to the complexity of relationship between vegetation and environmental conditions.

4.5 Vegetation patterns, coverage and degradation

Environmental variation is expected to have a strong influence on vegetation patterns (Russell, 2001; Cogbill, 2002; Foster, 2002), while plant spatial patterns may respond to changed conditions (Couteron, 2001; Rietkerk, 2002). So in the lower reaches of the Tarim River, the variation of vegetation in cover, number of species, species density and the relative proportion of woody plants just reflected the environmental variation (Fig.4).

Cover amongst different plant life-forms groups (Fig. 10), showed different trends for degradation. Of these, the coverage of *Populus euphratica* decreased little by little as the environmental factors varied. The cover of shrub did not decrease much more until at the intermediate stage of degradation. The different changes of trees and shrubs in cover might be explained by the well-known different behavior of both *Populus euphratica* and *Tamarix* spp. regarding seed germination, seedling survival or competition among adults (Guo, 1991; Yang, 1997). As for coverage of herbs, it showed an abruptly decreasing trend. At last, it would disappear firstly in the life-forms groups.

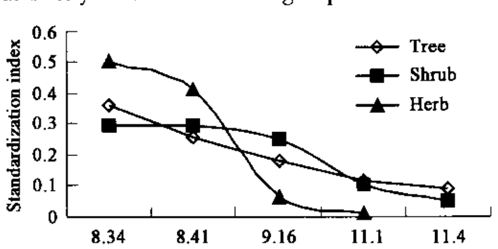

Fig. 10 The changes in the coverage of life-form groups under different groundwater depth

5 Conclusions

The results above presented suggested that plant species composition, plant community, cover percentage of plant life-forms groups, and the diversity index were suitable and complementary indices to evaluate vegetation degradation at the monitored sections. In the lower reaches of the Tarim River, the original *Populus euphratica* forests was established on the soils with a low natural quality, severely limited by natural aridity, salinity and sodicity as well as the water and sand erosion processes. The degradation of *Populus euphratica* forests due to water lack was jeopardized with serious consequences for desertification, species diversity and sustainable use of the natural environment. To maintain *Populus euphratica* regeneration and growth and prevent the ecological environment from further deterioration, some measures were strongly recommended for forming an integral management of water resources in the whole watershed, restricting the water diversion, reducing the inefficient water consumption at the upper and middle watershed and ensuring the ecological need of water in the lower reaches. So quantification of vegetation degradation and the extent of disturbance from humans and nature were important for future management to the river. In addition, recovery of the vegetation was presumably dependent on the extent of degradation when restoring measures were invoked, as well as management of water resources. It should be stressed that it may not be possible to re-establish the potential natural vegetation entirely, especially in the short term.

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