Landscape Ecol (2010) 25:1447–1455
DOI 10.1007/s10980-010-9505-y

RESEARCH ARTICLE

Patch-level based vegetation change and environmental drivers in Tarim River drainage area of West China

Weijing Kong · Osbert Jianxin Sun · Yaning Chen · Yi Yu · Ziqiang Tian

Received: 29 December 2009 / Accepted: 21 June 2010 / Published online: 2 July 2010

Abstract Information on vegetation-related land cover change and the principle drivers is critical for environmental management and assessment of desertification processes in arid environments. In this study, we investigated patch-level based changes in vegetation and other major land cover types in lower Tarim River drainage area in Xinjiang, West China, and examined the impacts of environmental factors on those changes. Patterns of land cover change were analyzed for the time sequence of 1987–1999–2004 based on satellite-derived land classification maps, and their relationships with environmental factors were determined using Redundancy Analysis (RDA). Environmental variables used in the analysis included altitude, slope, aspect, patch shape index (fractal dimension), patch area, distance to water body, distance to settlements, and distance to main roads. We found that during the study period, 26% of the land experienced cover changes, much of which were the types from the natural riparian and upland vegetation to other land covers. The natural riparian and upland vegetation patches were transformed mostly to desert and some to farmlands, indicating expanding desertification processes of the region. A significant fraction of the natural riparian and upland vegetation experienced a phase of alkalinity before becoming desert, suggesting that drought is not the exclusive environmental driver of desertification in the study area. Overall, only a small proportion of the variance in vegetation-related land cover change is explainable by environmental variables included in this study, especially during 1987–1999, indicating that patch-level based vegetation change in this region is partly attributable to environmental perturbations. The apparent transformation from the natural riparian and upland vegetation to desert indicates an on-going process of desertification in the region.

Keywords Arid environment · Desertification · Environmental perturbations · Patch dynamics · RDA · Vegetation change · West China

W. Kong · O. J. Sun (✉)
MOE Key Laboratory for Silviculture and Conservation and Institute of Forestry and Climate Change Research, Beijing Forestry University, 35 Qinghua East Road, Haidian District, Beijing 100083, China
e-mail: sunjianx@bjfu.edu.cn

W. Kong · Z. Tian
Riverine Ecology Research Center, Chinese Research Academy of Environmental Sciences, Beijing 100012, China

Y. Chen
Key Laboratory of Oasis Ecology and Desert Environment, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China

Y. Yu
International Centre for Bamboo and Rattan, Beijing 100102, China

Introduction

Vegetation change is one of the focal concerns among various landscape transitions because plants are primary drivers and mediators of ecosystem processes. Assessment of changes in vegetation pattern helps with gaining insight on ecosystem susceptibility to natural and anthropogenic perturbations, which is a particularly important issue in arid regions where ecosystem structure is simple and can be highly vulnerable to disturbance (Kraaij and Milton 2006; Katjiua and Ward 2007; Hou et al. 2007b). Moreover, identification of environmental factors responsible for vegetation change is critical for biological conservation and policy making in natural ecosystem management, and is seen scientifically as one of the main research themes in landscape ecology (Wu and Hobbs 2002).

The relationships between vegetation change and environmental factors vary spatially and with time, driven by differences in a number of factors including ecosystem types, climatic conditions, and the extent of environmental perturbation (Lameire et al. 2000; Ryerson and Parmenter 2001; Elke et al. 2004; Rolon et al. 2008). While some studies show close relationships between vegetation change and environmental factors (e.g. Pan et al. 1999; Chen et al. 2001), there are also evidences of weak linkage when anthropogenic activities over-dominate the influences of natural processes (e.g. Iverson 1988; Schneider and Pontius 2001). In different ecosystems, vegetation change has been associated with different environmental factors. For example, in the tropical rain forests, vegetation change is found to relate mainly to anthropogenic activities such as cultivation and wood harvesting (Burgos and Manuel Maass 2004); in arid and semiarid regions, natural vegetation change can be attributed to a variety of natural and anthropogenic factors such as changing ground water availability (White et al. 2008), changing rainfall patterns (Fensham et al. 2005), and grazing (Kraaij and Milton 2006; Rahlao et al. 2008).

Vast areas in western China have an arid climate due to blockage of southwesterly moist air from the Indian Ocean by the Himalayas, and a continental position that places the region far from easterly moist air from the Pacific. As a result, the regional vegetation structure is simple and productivity is low, making the ecosystems vulnerable to desertification processes. One of the areas of particular environmental concerns is the Tarim Basin in Xinjiang. In recent decades, a combination of climate change, increasing population pressure, and expanding agricultural land use has contributed to extensive ecosystem degradation and desertification in this region, with the impact being particularly intense over the past 20–30 years (Hou et al. 2007a). A previous study by Kong et al. (2009) shows that the areas along the lower Tarim River experienced landscape change in different directions between 1986 and 2004 in response to fluctuations in water-flow of the river; the vegetation area and NDVI decreased with declining water-flow during 1986–1999, but increased during 1999–2004 when an emergency water diversion program was implemented to maintain a regular water supply. For areas further away from the river, there are patterns of vegetation change apparently associated with two major processes known to play significant roles in driving the landscape transformation of the region: agricultural production and desertification (Kong et al. 2009). However, it remains unclear as how much of the landscape transformation and desertification processes in the region are attributable to natural environmental perturbations as compared with the influences of anthropogenic activities, and what are the key controlling environmental factors of the regional land cover changes.

Land cover change can occur at temporal scales ranging from years to centuries and hierarchical spatial scales from plots to patches to landscape (Wu and Loucks 1995). The development and availability of various air-borne and satellite remote sensing products have helped with rapidly advancing spatial and temporal land cover analysis, and with the aid of ordination methods, made it feasible to assess the relative importance of multiple environmental variables in driving land cover changes (Pan et al. 1999; Lepš and Šmilauer 2003; Elke et al. 2004).

In this study, we investigated patch-level based changes in vegetation and other major land cover types in lower Tarim River drainage area in Xinjiang, West China, and examined the impacts of environmental factors on those changes. Patterns of land cover change were analyzed for the time sequence of 1987–1999–2004 based on satellite-derived land classification maps, and their relationships with environmental factors were determined using Redundancy Analysis (RDA). Environmental variables used in the analysis were altitude, slope, aspect, patch shape index (fractal dimension), patch area, distance to water body, distance to settlements, and distance to main roads. Altitude, slope, and aspect were used as topographical attributes relating to thermal and water environments of the habitat. The distance to water body, settlements, and main roads was used as surrogates for availability of water supply and potential influences of anthropogenic activities. Our aims were to: (1) determine the patterns of spatial and temporal changes in vegetation cover and the recent landscape transformation in the study area; and (2) identify the major environmental factors contributing to desertification processes of the region. We focused primarily on land cover changes originated from the natural vegetation.

Methods

Study area

This study was conducted in the lower Tarim River drainage area in central Xinjiang, West China, in the section between the Qiala Reservoir (construction started in 1958 and completed in 1967, and further expanded in 1989) to the Daxihaizi Reservoir (constructed in 1972) and over an area of 2600 km^2 (Fig. 1). The area is surrounded by the Takelamakan Desert in the south and the Kuluktag Desert in the north. Annual rainfall is often less than 50 mm (Chen et al. 2004). Vegetation in the riparian corridor and the upland consists of predominantly halophytic plants in the family of Salicaceae, Tamaricaceae, Leguminosae, Apocynaceae and Gramineae (Zhang et al. 2005). *Populus euphrarica* Oliv. is the major tree species in the riparian zone; shrubs include *Nitraria sibirica* Pall., several *Tamarix* species, and *Halimodendron halodendron* (Pall.) Voss. *Phragmites communis* Trin. dominates the herbage layer and co-occurs with *Glycyrrhiza inflata* Batal., *Alhagi sparsifolia* Shap., and other minor species (Chen et al. 2006).

Beginning in the late 1960s, some lands in the lower Tarim River region were cultivated by migrant settlers for growing food crops and cotton, or converted to orchards and deer farms. The cultivated areas rapidly expanded, doubling from 35120 km^2 in 1949 to 77660 km^2 in 1993, along with a sharp increase in population (Hou et al. 2007a).

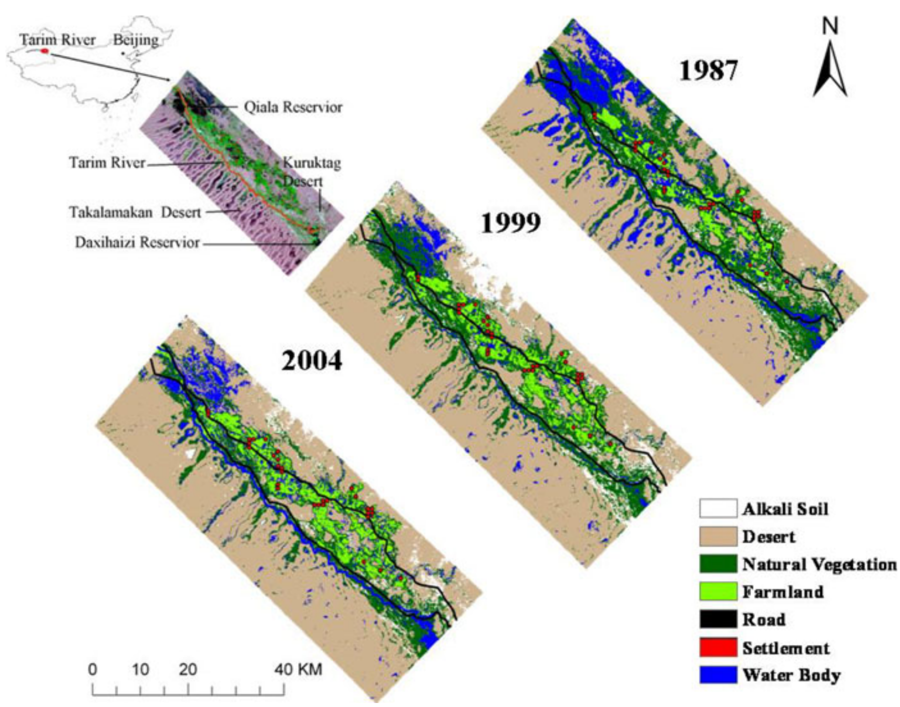

Fig. 1 Location of study area in Tarim Basin, West China, and land classification maps for 1987, 1999, and 2004

Data collection and processing

Data on land cover change were obtained by comparing land classification maps for 1987, 1999, and 2004 (Fig. 1), which were derived from Landsat TM images in orbit 14232 with supervised maximum likelihood classification method (Bresee et al. 2004). The images were acquired on 15 September 1987, 30 July 1999, and 13 September 2004. They were selected by taking into account image data availability and quality, timing consistency for identification of ground objects, and ability to distinguish growth season vegetation cover. All images were processed against a geometrically corrected TM image of 2001 for the study area (http://glcf.umiacs.umd.edu/data), which was made with reference to ground control points in polynomial transformation and precision to one pixel, and projected to Albers equal area projection. The land classification system consisted of seven land cover types: natural riparian and upland vegetation (*V*), farmland (*F*), desert (*D*), alkali soil (*A*), water body (*W*), settlement (*S*), and road (*R*). Natural riparian and upland vegetation includes pure or mixed *Populus euphratica* forests, *Tamarix* bushes, and halophytic meadows. *Popular euphratica* forests grow mainly along the river channel, floodplain, and old river channel, often occurring as pure sparse woodlands or in mixture with *Tamarix* spp. *Tamarix* bushes occur on inter-dune flats, along the river channel or in sandy desert. Halophytic meadows are found extensively throughout the area. The farmlands are the results of agricultural production by migrant settlers since 1950s, currently with cotton as a key crop and irrigation water drawn out of the Qiala Reservoir and the Tarim River. Desert is the dominant land cover type of the study area and contains sparsely distributed xerophytes in extremely low coverage. Alkali soils occur extensively in places near water body and result mostly from high groundwater table. Water body includes water-filled river channel, reservoir, and seasonal flood pools. Settlement refers to the residential area. More detailed information on study area is given in Kong et al. (2009).

Different ground objects, i.e. the classified cover types, were distinguished by spectral and textural features. The accuracy of land classification maps was assessed with 200 ground-truth datum points from field surveys and Google Earth data based on 2004 imagery at 1.0 m or 0.61 m resolution (Kong et al. 2009). The application of Google Earth data in accuracy assessment of the historical images was restricted to land cover types and places that were not expected to experience apparent changes over the study period. The values of classification accuracy on land cover types were all greater than 88% for the three assessment years and well above the acceptable level (Xie et al. 2008).

Environmental variables included altitude, slope, aspect, patch shape index (fractal dimension), patch area, distance to water body, distance to settlements, and distance to main roads (Table 1). Altitude, slope, and aspect were selected as topographical attributes reflecting the thermal and water environments of the habitat. The distance to water body, settlements, and main roads was used as surrogates for accessibility to water and potential influences of anthropogenic activities. Analysis on the relationships of vegetation change with topographical and spatial attributes was made at patch-level.

Information on altitude was derived from SRTM DEM data produced by NASA and the USGS National Imagery and Mapping Agency (NIMA) at 90-m resolution (http://srtm.csi.cgiar.org). The altitude data

Table 1 Environmental variables that were analyzed with land cover trajectory

Environmental Variables	Value range	Mode	Standard deviation
Altitude (m)	845–930	878	9.01
Slope	1–7	2	
Aspect	1–9	9	
Patch area (ha)	0.18–62807		2195
Fractal dimension	1.31–1.59	1.39	0.04
Distance to settlement (*PopDis*; m)	362–24713	1114	4973
Distance to water body (*WBDis*; m)	0–14677	604	3014
Distance to main roads (*Rdis*; m)	6–17534	2914	3780

were resampled to match the resolution of land classification maps. Information on aspect and slope was derived from the DEM product using spatial analyst function in ArcGIS 9.0. The aspect was categorized into nine groups: O, flat terrain; N, 0–22.5° and 337.5–360°; NE, 22.5–67.5°; E, 67.5–112.5°; SE, 112.5–157.5°; S, 157.5–202.5°; SW, 202.5–247.5°; W, 247.5–292.5°; and NW, 292.5–337.5°. The slope was classified into seven categories in ascending values as 1, 0–1°; 2, 1–3°; 3, 3–6°; 4, 6–9°; 5, 9–12°; 6, 12–30°; and 7, 30–90°. Both slope and aspect were assigned to particular values for direct gradient analysis (Elke et al. 2004). In case there were multiple slope or aspect values for a given patch, the dominant slope or aspect was used.

Patch area was calculated from the vector classification maps, and patch shape was assessed as fractal dimension, which equals twice the logarithm of patch perimeter divided by the logarithm of patch size (McGarigal and Marks 1995). Values of fractal dimension range from 1 for shapes with very simple perimeters, such as a square, to 2 for shapes with highly convoluted perimeter of complex shape (McGarigal and Marks 1995).

Distance of vegetation patch to water body, main roads, and settlements was defined as the distance from the patch center to the nearest edge of the target objects. The settlement coordinates were extracted from the 1-km resolution global population grid-map of 2004 (http://www.ornl.gov).

Land cover change analysis

Trajectories were used to express the land cover change (Mertens and Lambins 2000). In this study, land cover trajectory is defined as time sequences at patch-level of the three successive land cover layers (the land classification maps) for 1987, 1999, and 2004 (e.g. a trajectory can be *VFD* or *VVF*, where V = natural vegetation, F = farmland, D = desert). To introduce these trajectories into the subsequent analysis, qualitative land cover data were binary coded to presence–absence format (Elke et al. 2004). Vegetation-related land cover transition types at patch-level and their relationships with environmental variables were also examined for the time intervals of 1987–1999 and 1999–2004.

Relationships between vegetation change and environmental variables were analyzed using direct gradient analysis. There are several direct gradient analysis methods and the length of environmental gradients determines the appropriate method to be used (Lepš and Šmilauer 2003). We tested the length of the environmental gradients using Detrended Correspondence Analysis (DCA) with non-linear rescaling of the axes (Lepš and Šmilauer 2003). Results revealed a length of the environmental gradient of <3 SD in all analyses, indicating Redundancy Analysis (RDA) as the most appropriate method (Lepš and Šmilauer 2003).

RDA analysis of the relationships of land cover change trajectory type for the whole study period and land cover transition type for each of the time intervals with environmental variables was performed using the Canoco 4.0. Associations of various types of land cover transitions and trajectories with specific environmental variables were assessed by making joint plots in the Canoco. The significance level of the relationships was calculated with Monte Carlo permutation tests (Lepš and Šmilauer 2003).

Results

Land-cover trajectories

Sixty-five types of land cover trajectories were identified for the time sequence 1987–1999–2004, of which most were related to desertification, and only a few to changes concerning farmland. The natural riparian and upland vegetation decreased by 36% in area, and desert and farmlands increased by 18 and 80%, respectively (Table 2). Among all land cover types, desert accounted for the largest percentage, of which 53% remained unchanged between 1987 and 2004; of the study area, 26% experienced land cover change, with the natural riparian and upland vegetation changing the most. Transformations to desert (trajectory types *VDD*, *VAD* and *VVD*), farmland (trajectory types *VFF* and *VVF*), and alkali soil (trajectory type *VAA*) accounted for approximately 6%, 3%, and 1% of the total area for the natural riparian and upland vegetation. Trajectories that indicate vegetation degradation and subsequent recovery (trajectory types *VAV* and *VDV*) accounted for only 0.8% of the study area.

There are distinct spatial patterns of vegetation-related land cover changes (Fig. 2). Areas that

Table 2 Areas (hectare) by land cover types for 1987, 1999 and 2004 and rate of change between assessment years in the study area of Tarim Basin, West China

Land-cover types	1987	1999	2004	Rate of change (%)		
				87–99	99–04	87–04
Farmland	10981	15325	19710	39.6	28.6	79.5
Natural riparian & upland vegetation	71370	61470	45685	−13.9	−25.7	−36.0
Desert	142872	158036	168474	10.6	6.60	17.9
Alkali soil	7095	17440	8906	145.8	−48.9	25.5
Water body	30097	9956	19349	−66.9	94.3	−35.7
Settlement	241	353	374	46.5	5.9	55.2
Road	–	209	313	–	49.8	–

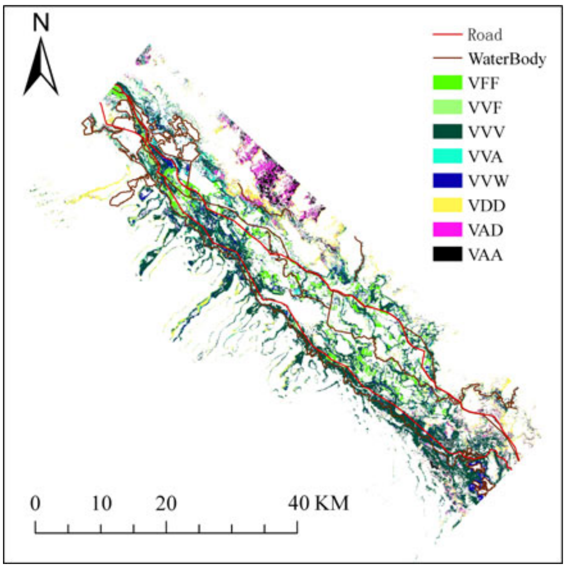

Fig. 2 Spatial pattern of vegetation-related land cover change trajectories for the time sequence 1987–1999–2004 in the study area of Tarim Basin, West China. *V* natural riparian and upland vegetation, *F* farmland, *A* alkali soil, *W* water body, *D* desert

transformed to farmlands are mostly distributed along the roads and near the river channel; those to desert are generally in places distant to the river and distant to water-covered areas. A significant fraction of the natural riparian and upland vegetation experienced a phase of alkalinity before becoming desert (i.e. trajectory type *VAD* in Fig. 2).

Relationship between land cover change and environmental variables

For the time sequence 1987–1999–2004, the lands with unchanged natural riparian and upland vegetation (trajectory type *VVV*) had a positive correlation with altitude. The changes from the natural riparian and upland vegetation to farmland, i.e. the trajectory types *VFF* and *VVF*, were highly and positively correlated with distance to settlement, and negatively with distance to water body and distance to roads (Fig. 3). In contrast, the changes from the natural riparian and upland vegetation to desert appeared to widely diverge in relation to environmental variables, depending on the interim land cover type. While the trajectory type *VDD* was highly and positively correlated with distance to water body and distance to roads, the trajectory type *VVD* was positively correlated with altitude and distance to settlement; whereas the trajectory type VAD was negatively correlated with distance to water body, aspect, and slope (Fig. 3). The trajectory type *VAA* was negatively correlated with slope and altitude.

Land-cover changes were mainly correlated with altitude and distance to water body (WBDis) during 1987–1999, and with patch shape index and distance to settlement (PopDis) during 1999–2004 (Fig. 4). For both time sequences, the environmental variables explained only a small fraction of the variance in vegetation-related land cover changes; the variance accountable by environmental variables was higher during 1999–2004, at 19.3%, than during 1987–1999, at merely 6.7%.

Discussion

In this study, we found highly variable landscape matrix with time in the lower Tarim River drainage area of West China for the time sequence 1987–1999–2004; vegetation-related land cover changes during 1987–2004 were mostly from the natural

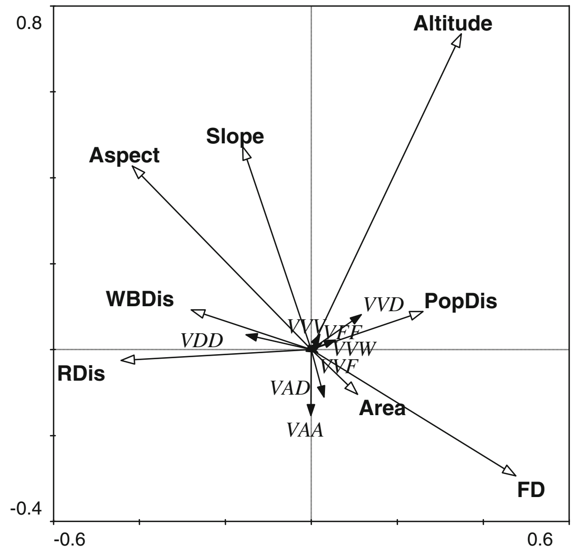

Fig. 3 RDA ordination of vegetation-related land cover change trajectory (*lines with filled arrowheads*) in relation to environmental variables (*lines with open arrowheads*) for time sequence of 1987–1999–2004 in the study area of Tarim Basin, West China. *FD* fractional dimension, *PopDis* distance of vegetation patch to settlement, *WBDis* distance of vegetation patch to water body, *RDis* distance of vegetation patch to the main roads. *Arrow-lines* represent relative values of environmental variables and land cover change trajectories. Correlations between environmental variables and land cover change trajectories are indicated by the cosine of angles between the corresponding *arrow-lines*; angles <90° indicate a positive correlation, and >90° a negative correlation. Projecting the *arrow-line* for a land cover change trajectory into an *arrow-line* for a corresponding environmental variable, the distance from the origin to the projection point indicates the relative value of the environmental variable where the land cover transition is most likely to occur

riparian and upland vegetation to desert and some to farmlands. Studies based on field survey indicate that variations in river water-flow play a major role in determining the vegetation cover and structure by influencing groundwater systems along the Tarim River (Chen et al. 2006). However, the impact of river water-flow has been shown to be largely restricted to the riparian zone of the study area (Kong et al. 2009), and is thus not likely the cause of desertification in the greater Tarim River drainage area. Expanding farmlands are known to greatly increase water consumption due to irrigation in this region, possibly contributing to desertification processes by influencing groundwater availability to

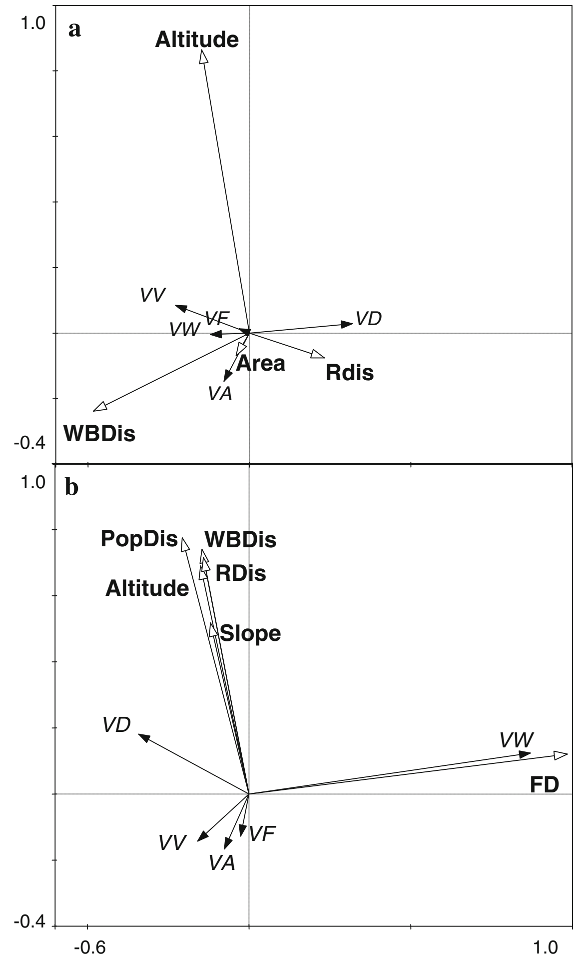

Fig. 4 RDA ordination of vegetation-related land cover transformation during 1987–1999 (**a**) and 1999–2004 (**b**) in the study area in Tarim Basin, West China. *VV* stable natural riparian and upland vegetation, *VA* transformation of natural riparian and upland vegetation to alkali soil, *VD* transformation of natural riparian and upland vegetation to desert, *VF* transformation of natural riparian and upland vegetation to farmland, *VW* transformation of natural riparian and upland vegetation to water body. Only environmental variables showing correlation coefficients ≥0.07 on either RDA axes are plotted in the diagram. *Arrow-lines* represent relative values of environmental variables and land cover change trajectories. Correlations between environmental variables and land cover change trajectories are indicated by the cosine of angles between the corresponding *arrow-lines*; angles <90° indicate a positive correlation, and >90° a negative correlation. Projecting the *arrow-line* for a land cover change trajectory into an *arrow-line* for a corresponding environmental variable, the distance from the origin to the projection point indicates the relative value of the environmental variable where the land cover transition is most likely to occur

natural vegetation. However, we were not able to directly determine this effect due to lack of spatially-explicit information on groundwater for the study area. A previous study by Chen et al. (2006) shows that, declining groundwater level along the lower Tarim River is directly responsible for the degradation and die-back of the riparian vegetation.

Changes of the natural riparian and upland vegetation to farmlands reflected the influences of expanding agricultural activities in the region. This land cover change type occurred close to water bodies and roads, clearly for reasons of access to irrigational water source and practical operation. It has been long and widely recognized that increasing food demand for rapidly expanding population is the very cause of land cover change as the main anthropogenic disturbance to vegetation in arid regions (Puigdefábregas 1998; Lambin et al. 2001; Chen et al. 2006; Reynolds et al. 2007). Demand for increased food production has turned many of the rain-fed farming systems to irrigated agriculture worldwide (Klein Goldewijk 2001; Chen et al. 2003; Scanlon et al. 2007). Rapidly expanding world population and climate change can both impose significant impact on global water resources (Vorosmarty et al. 2000), intensifying the desertification processes in arid regions.

Spatially, the natural vegetation remained mostly unchanged along the riparian zones along the Tarim River as compared with locations distant to river channel and water covered areas. It also needs to be specifically noted that a large fraction of land cover change from natural vegetation to desert went through an interim phase of alkali soils during the study period, indicating a pathway of ecosystem degradation by salinity and alkalinity apart from drought in the study area. This suggests that in this arid region, drought is not the exclusive environmental driver of desertification. Irrigation based on surface water in agricultural system may contribute to vegetation degradation via salinity in waterlogged areas, as being observed to widely occur globally when natural ecosystems are converted to agricultural land use (Scanlon et al. 2007). In the Murray Darling basin of the arid southeastern Australia, a large-scale clearance of the native forests for agricultural production has been seen to result in raising groundwater level, which leads to salinity of the lands and consequently a decline in plant cover (Allison et al. 1990). This supports our findings here that the transformation of the natural riparian and upland vegetation to alkali soils occurred mostly on low-laying flat terrain and near water bodies, as indicated by the negative correlations of the changes to alkali soils with altitude, slope, and distance to water body (Fig. 3).

Our results indicate that only a small proportion of the variance in vegetation-related land cover change is explainable by environmental variables, especially during 1987–1999. Inability to incorporate spatial data on soil properties, groundwater table, and rainfall has constrained our capability for more accurately identifying drivers of landscape transformations in the lower Tarim River drainage area. Nonetheless, our findings suggest that patch-level based vegetation change in this region is partly attributable to environmental perturbations. The apparent transformation from the natural riparian and upland vegetation to desert indicates the ongoing process of desertification in the region.

Acknowledgments This study was jointly supported by the Ministry of Science and Technology of China (grant 2008BADB0B0302), the State Forestry Administration of China (grant 200804001), the Chinese Academy of Sciences (grant 90502004), and the National Natural Science Foundation of China (grant 30500081). We are grateful to the Coordinating Editor and two anonymous reviewers for help with improving the writing of the manuscript.

References

Allison GB, Cook PG, Barnett SR, Walker GR, Jolly ID, Hughes MW (1990) Land clearance and river salinization in the western Murray Basin, Australia. J Hydrol 119:1–20

Bresee MK, Moine JL, Mather S, Brosofske KD, Chen J, Crow TR, Rademacher J (2004) Disturbance and landscape dynamics in the Chequamegon National Forest Wisconsin, USA, from 1972 to 2001. Landscape Ecol 19:291–309

Burgos A, Manuel Maass J (2004) Vegetation change associated with land-use in tropical dry forest areas of Western Mexico. Agric Ecosys Environ 104:475–481

Chen LD, Wang J, Fu BJ, Qiu Y (2001) Land-use change in a small catchment of northern Loess Plateau, China. Agric Ecosys Environ 86:163–172

Chen J, He D, Cui S (2003) The response of river water quality and quantity to the development of irrigated agriculture in the last 4 decades in the Yellow River Basin, China. Water Resour Res 39:W01047. doi:10.1029/2001WR001234

Chen YN, Zhang XL, Zhu XM, Li WH, Zhang YM, Xu HL, Zhang HF, Chen YP (2004) Analysis on the ecological benefits of the stream water conveyance to the dried-up river of the lower reaches of Tarim River, China. Sci China Ser D 47:1053–1064

Chen YN, Zilliacus H, Li WH, Zhang HF, Chen YP (2006) Ground-water level affects plants species diversity along the lower reaches of the lower Tarim River, Western China. J Arid Environ 26:231–246

Elke H, Rainer W, Annette O (2004) Analyzing land-cover changes in relation to environmental variables in Hesse, Germany. Landscape Ecol 19:473–489

Fensham RJ, Fairfax RJ, Archer SR (2005) Rainfall, land use and woody land cover change in semi-arid Australia Savanna. J Ecol 93:596–606

Hou P, Beeton RJS, Carter RW, Dong XG, Li X (2007a) Response to environmental flows in the lower Tarim River, Xinjiang, China: ground water. J Environ Manage 83:371–382

Hou P, Beeton RJS, Carter RW, Dong XG, Li X (2007b) Response to environmental flows in the Lower Tarim River, Xinjiang, China: an ecological interpretation of water-table dynamics. J Environ Manage 83:383–391

Iverson LR (1988) Land-use change in Illinois, USA: the influence of landscape attributes on current and historic land use. Landscape Ecol 2:45–62

Katjiua M, Ward D (2007) Pastoralists' perceptions and realities of vegetation change and browse consumption in the northern Kalahari, Namibia. J Arid Environ 69:716–730

Klein Goldewijk K (2001) Estimating global land use change over the past 300 years: the HYDE Database. Global Biogeochem Cycles 15:417–433

Kong W, Sun OJ, Xu W, Chen Y (2009) Changes in vegetation and landscape patterns with altered river water-flow in arid West China. J Arid Environ 73:306–313

Kraaij T, Milton SJ (2006) Vegetation changes (1995–2004) in semi-arid Karoo shrubland, South Africa: effects of rainfall, wild herbivores and change in land use. J Arid Environ 64:174–192

Lambin EF, Turner BL II, Geist HJ, Agbola S, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skanes H, Steffen W, Stone GD, Svedin U, Veldkamp A, Vogel C, Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. Global Environ Change 11:261–269

Lameire S, Hermy M, Honnay O (2000) Two decades of changes in the ground vegetation of a mixed deciduous forest in an agricultural landscape. J Veg Sci 11:695–704

Lepš J, Šmilauer P (2003) Multivariate analysis of ecological data using *CANOCO*. Cambridge University Press, Cambridge, UK

McGarigal K, Marks BJ (1995) FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, 122 p

Mertens B, Lambin EF (2000) Land cover change trajectories in southern Cameroon. Ann Assoc Am Geogr 90:467–494

Pan D, Domon G, de Blois S, Bouchard A (1999) Temporal (1958–1993) and spatial patterns of land use changes in Haut-SaintLaurent (Quebec, Canada) and their relation to landscape physical attributes. Landscape Ecol 14:35–52

Puigdefábregas J (1998) Ecological effects of global change on drylands and their implications for desertification. Land Degrad Dev 9:393–406

Rahlao SJ, Hoffman MT, Todd SW, McGrath K (2008) Long-term vegetation change in the Succulent Karoo, South Africa following 67 years of rest from grazing. J Arid Environ 72:808–819

Reynolds JF, Smith DMS, Lambin EF, Turner BL, Mortimore M, Batterbury SPJ, Downing TE, Dowlatabadi H, Fernández RJ, Herrick JE, Huber-Sannwald E, Jiang H, Leemans R, Lynam T, Maestre FT, Ayarza M, Walker B (2007) Global desertification: building a science for dryland development. Science 316:847–851

Rolon AS, Lacerda T, Maltchik L, Guadagnin DL (2008) Influence of area, habitat and water chemistry on richness and composition of macrophyte assemblages in southern Brazilian wetlands. J Veg Sci 19:221–228

Ryerson DE, Parmenter RR (2001) Vegetation change following removal of keystone herbivores from desert grasslands in New Mexico. J Veg Sci 12:167–180

Scanlon BR, Jolly I, Sophocleous M, Zhang L (2007) Global Impacts of conversions from natural to agricultural ecosystems on water resources: quantity versus quality. Water Resour Res 43:W03437. doi:10.1029/2006WR005486

Schneider LC, Pontius RG (2001) Modeling land-use change in the Ipswich watershed, Massachusetts, USA. Agric Ecosys Environ 85:83–94

Vorosmarty CJ, Green P, Salisbury J, Lammers RB (2000) Global water resources: vulnerability from climate change and population growth. Science 289:284–288

White JD, Gutzwiller KJ, Barrow WC, Randall LJ, Swint P (2008) Modeling mechanisms of vegetation change due to fire in a semi-arid ecosystem. Ecol Model 214:181–200

Wu J, Hobbs R (2002) Key issues and research priorities in landscape ecology: an idiosyncratic synthesis. Landscape Ecol 17:355–365

Wu J, Loucks OL (1995) From balance of nature to hierarchical patch dynamics: a paradigm shift in ecology. Quart Rev Biol 70:439–466

Xie YC, Sha ZY, Yu M (2008) Remote sensing imagery in vegetation mapping: an overview. J Plant Ecol 1:9–23

Zhang YM, Chen YN, Pan BR (2005) Distribution and floristics of desert plant communities in the lower reaches of Tarim River, southern Xinjiang, People's Republic of China. J Arid Environ 63:772–784