ORIGINAL ARTICLE

Driving forces behind land use and cover change in the Qinghai-Tibetan Plateau: a case study of the source region of the Yellow River, Qinghai Province, China

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Abstract Research on land use and cover change (LUCC) is an important aspect of the study of global change or global warming. The Qinghai-Tibetan Plateau is a good place to study global change because of its unique natural conditions, so we chose the source region of China's Yellow River for a case study of the driving forces behind LUCC. We used Landsat images obtained in 1989, 2000, and 2005 to establish databases of land use and cover at these times. We then derived LUCC information by overlaying these layers using GIS software. By studying the processes responsible for LUCC, we analyzed the driving forces, which included climatic change, human activities, animal and insect damage, and the influences of government policies. During the 16-year study period, LUCC occurred slowly in response to two groups of processes: natural and anthropogenic. The main driving forces included climate change (the region is becoming drier and warmer), human activities (especially overgrazing), and animal and insect damage. Although political measures such as key national projects to improve the ecological environment could help to restore the region's vegetation and slow desertification, the region's fragile ecosystems and harsh natural conditions will make it extremely difficult to rehabilitate the eco-environment.

Keywords Land use and cover change · Driving forces · Source region of the Yellow River

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Introduction

Since land use and cover change (LUCC) was first treated as a core joint project of the International Geosphere-Biosphere Program and the International Human Dimensions Programme on Global Environment Change in 1995, the study of LUCC in typical environmentally fragile regions has become an important area of research (Li 1996). Land cover (the biophysical attributes of the earth's surface) and land-use change (how humans affect these attributes) play an important role in current global change and global warming phenomena (Vitousek et al. 1992), so research on LUCC is necessary for us to understand global change. The Qinghai-Tibetan Plateau is a good place to study the effects of global climate change, since its local climatic changes are closely related to overall global environmental change (Zheng and Li 1999), which drives and amplifies local climatic changes (Pan and Li 1996). LUCC is one component of the global environmental changes that are currently underway, though its effects may

be outweighed by those of fossil fuel consumption and its effects on atmospheric warming (Steffen et al. 2002).

The source region of China's Yellow River is located in the northeastern part of the Qinghai-Tibetan Plateau. Because of the region's fragile and sensitive eco-environment, changes in its eco-environment have been significant in recent years. The source region of the Yellow River, in Qinghai Province, is located in a typical part of the northeastern Qinghai-Tibetan Plateau, far from oceans or other large bodies of water. The region is characterized by low temperatures, relatively low and highly variable precipitation, frequent strong winds, high potential evaporation, a thin vegetation cover, and an abundance of fine particles in the surface sediments. During the past 20 years, the difficult natural conditions and irrational human activities (including overgrazing and over-reclamation of land for agriculture) have led to increasing numbers of eco-environmental problems, such as desertification, grassland degradation, reduced runoff into rivers, decreased sizes of ponds and other bodies of water, and increased soil erosion.

The technologies and methods of remote sensing have evolved dramatically, and now include a suite of sensors with different spatial resolutions and temporal frequencies, so remote sensing has become a useful tool for gathering data on environmental changes over wide areas (Runnstrom 2003). For example, the Landsat series provides more than 30 years of satellite images with high spatial resolution that offer a "unique view" of the spatial and temporal dynamics of the processes involved in LUCC. Satellite remote sensing techniques have therefore been widely used to detect and monitor such changes at a range of scales, with useful results (e.g., Stefanov et al. 2001; Wilson et al. 2003). In particular, remote sensing data has been combined with Geographical Information Systems (GIS) and Global Positioning Systems (GPS) technology to assess changes with increasing effectiveness (Müller and Zeller 2002; Weng 2002). Remote sensing is now a proven tool in land-use mapping. In the present study, we used Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) images to establish a high-precision land use and cover database for the source region of the Yellow River, and used this data to detect and evaluate LUCC during this 16-year period. Our objectives were to:

- explore the evolution of land use and cover during this period;
- detect and examine land use and cover, and use this data to produce land-use maps for 1989, 2000, and 2005;
- provide support for strategic decision-making to guide landscape-level planning and protection of the study region's eco-environment.

Study area

Our study focused on the source region of the Yellow River, which includes the catchments above the Longyang Gorge between 95°50′E and 103°25′E and between 32°8′N and 36°35′N, an area that covers approximately 1.3×10^5 km^2 (Fig. 1) in the hinterland of the Qinghai-Tibetan Plateau. The mean elevation is >3,000 m asl. The

Fig. 1 Map of the source region of the Yellow River
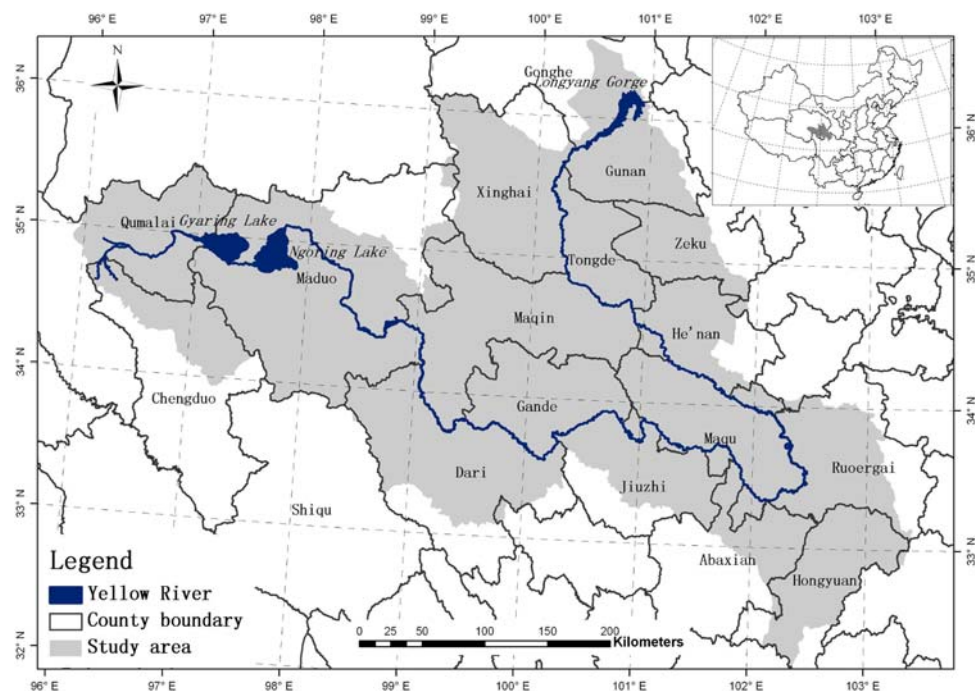
source region, which is high in the west and low in the east, has relatively low mountains, numerous lakes, and wide valleys (GICAS 1990). The prevailing climate is an alpine plateau continental climate, characterized by cold and dry weather, without strong seasonal variations. The annual mean air temperature is −2.3°C (ranging from −13.6°C in January to 11.3°C in July), without a frost-free season, and the annual mean precipitation is 411 mm, most of which falls as snow or heavy rain (Feng et al. 2004). The vegetation consists largely of high cold meadows (the dominant vegetation type), high cold steppes, alpine meadows, and swamp meadows (Wang et al. 2000). The high cold meadows are dominated by *Kobresia* species. The high cold steppes are dominated by *Stipa purpurea* var. *arenopsa* and *Poa anhua*, and are found mainly around Gyaring Lake and Ngoring Lake. The high cold meadows and steppes are the main pasturelands of the south Qinghai plateau and Qinghai Province. The main soil type is an alpine meadow soil, with small areas of swamp soil (Wang et al. 2001). The region is administered by the governments of Qinghai, Gansu, and Sichuan provinces, which include 24 counties. The region is underpopulated, with a population density ranging from 0.5 to 2 people per square kilometer, dominated by Tibetan herdsmen.

Materials and methods

Data sources

In this study, we used four sets of data. Landsat TM images with a spatial resolution of 30 m were acquired in 1989 and 2005, Landsat ETM+ images with the same spatial resolution were acquired in 2000. As it was difficult to acquire cloud-free images that covered the whole study area within a given year due to its large area, some images from 1990, 1999, and 2004 were chosen to replace unsuitable images from 1989, 2000, and 2005, respectively. During each time period, more than 15 images (scenes) were obtained to cover the study area.

Digital topographic maps and other thematic maps such as maps of regional desertification, climatic zones, and vegetation were digitized from hardcopy topographic maps with a scale of 1:100,000, and these images were used for geometric correction of the satellite images and to confirm the classification results.

Landscape images accurately positioned by means of GPS were acquired to assist in the interpretation of established signs and to improve classification accuracy.

We also collected the climatic records for use in analyzing the driving forces responsible for the observed LUCC.

Image pre-processing

Using the Image Analyst function of the Module GIS Environment (MGE) software(Intergraph Corporation, Huntsville, Alabama, U.S.), we georeferenced and ortho-rectified the 2000 ETM+ images using 50–60 ground control points (GCPs) derived from a 1:100,000 topographic map. The mean location error for this georectification was less than 1 pixel (i.e., <30 m). The 1989 TM images were matched with the 2000 images by means of an image-to-image matching method. During the image-matching process, we randomly selected 40–50 GCPs in 1989 and in 2000 in order to cover most of the area represented by the two sets of images. The root-mean-square (RMS) error of the geometrical rectification between the two images was 1–2 pixels (i.e., <60 m) for plains areas and 2–3 pixels (i.e., <90 m) for mountainous regions. We used the same method to process the 2005 TM images, with similar results.

Land use and cover classification

We used a system of six primary land cover types (farmland, forest, grassland, water, built-up land, and unused land) that were divided into 25 secondary types (Table 1). Visual interpretation was used to derive the LUCC information. Although the visual interpretation of TM and ETM+ images is labor intensive and time consuming, the mapping accuracy of this method is higher than that of image classification using only the algorithms provided by image-processing software because of the low spatial and spectral resolution of TM and ETM+ images (Liu 1996; Zhuang et al. 1999).

We used the freehand drawing function of the MGE software to delineate and label regions of the TM and ETM+ images by visually interactive interpretation to establish the LUCC databases for the three years. Based on the recognition ability of the TM and ETM+ images and

Table 1 The land cover type classification system used in this study

Primary types	Secondary types
Farmland	Paddy field, non-paddy field
Forest	Forest, shrubs, sparse forest, other forest
Grassland	Dense grassland, moderately dense grassland, sparse grassland
Water	River, lake, reservoir or pond, glacier or snow, beach, bottomland
Built-up area	Urban area, rural residential area, other built-up area
Unused land	Sandy land, gobi, saline land, marsh, bare land, bare rock, other unused land

the accuracy of the mapping, the manual visual interpretation and digitization of the TM and ETM + images was carried out at a scale of 1:100,000. During interpretation, we adopted the following mapping principles: (1) the minimum mapping patch was 7 × 7 pixels (equivalent to 210 × 210 m on the ground, or approximately 2 × 2 mm on the maps); (2) the deviation of delineating locations was less then 1 pixel on the screen (i.e., <30 m on the ground); and (3) the accuracy of labeling patches was greater than 96% based on our ground-truthing results. In addition to the TM and ETM+ images, we collected ancillary materials such as regional land-use maps, desertification maps, topographic maps, climatic zone data, vegetation maps, and field survey reports to assist in labeling the map patches during the interpretation process. After we completed the manual visual interpretation, we derived the land use and cover dynamics by overlaying the data layers for each year using the GIS software and summarizing the data using spreadsheet software, and created a matrix of land-use changes in order to determine the patterns of change during the study period.

Results

Land use and cover dynamics since 1989

Figure 2 shows the land use and cover data for 2005. Changes in the land use and cover mainly appeared near Gyaring Lake and Ngoring Lake, the Longyang Gorge, and in the southeastern part of the region. Grassland occupied the largest percentage of the land area throughout the study period (Table 2). The Farmland and built-up land experienced the most significant growth as a result of increasing population and unchecked land reclamation for agriculture; the two land uses both increased by more than 20 km^2 since 1989. The areas of forest and water had decreased by 2000, then increased again by 2005. Unused land showed the opposite trend; it increased by 2000, then decreased by 2005. This suggested that from 1989 to 2000, degradation of the eco-environment was the dominant trend, with the area of water decreasing, particularly for swamp meadows, and the area of low-quality grassland and unused land (sandy land, bare land) increasing. From 2000 to 2005, improvement of the eco-environment became the main trend, with rivers and lakes increasing in size and the areas of low-quality grassland and unused land (sandy land, bare land) decreasing.

LUCC processes

The transition matrices for LUCC from 1989 to 2000 (Table 3) and from 2000 to 2005 (Table 4) were calculated by overlaying the data layers for these three years. The results suggest that the processes responsible for LUCC could be divided into two different groups: natural and anthropogenic changes.

Natural and autogenic land-cover change processes include changes in the natural environment or indirect human influences on environment, but these processes are mainly caused by natural factors. From 2000 to 2005, natural processes accounted for more than 67% of the

Fig. 2 Map of land use and cover classes in the source region of the Yellow River in 2005
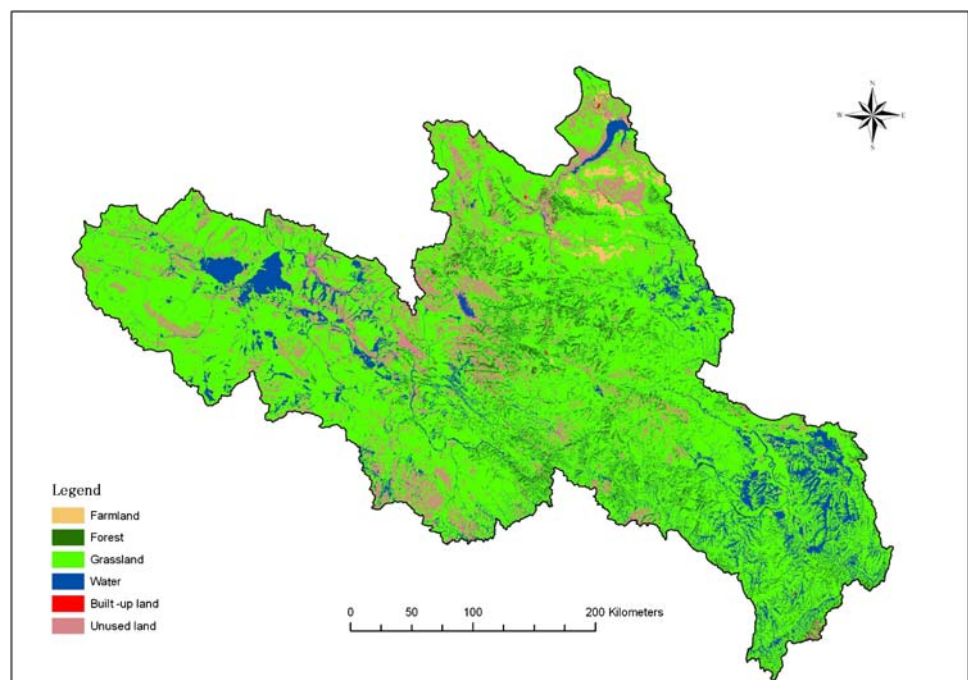
Table 2 The proportions of the total area of the region accounted for by each of the six LUCC types in 1989, 2000, and 2005

Land cover type	1989		2000		2005	
	Area (km^2)	% of total	Area (km^2)	% of total	Area (km^2)	% of total
Farmland	1,243.76	0.95	1,250.85	0.95	1,265.04	0.96
Forest	7,883.03	6.00	7,757.01	5.90	7,778.49	5.92
Grassland	94,155.48	71.64	94,366.20	71.81	94,283.73	71.74
Water	13,162.16	10.02	12,825.94	9.76	12,938.79	9.85
Built-up land	91.20	0.07	110.04	0.08	111.96	0.09
Unused land	14,884.37	11.33	15,109.96	11.50	15,041.99	11.45
Total	131,420.00	100.00	131,420.00	100.00	131,420.00	100.00

Table 3 Land use transfer matrix from 1989 to 2000

Change in area (km^2) by 2000

1989	Farmland	Forest	Grassland	Water	Built-up land	Unused land	Total
Farmland	1,154.84	0.00	77.96	1.17	7.71	2.08	1,243.76
Forest	0.00	7,657.91	222.27	1.36	0.17	1.32	7,883.03
Grassland	91.46	91.35	93,280.18	129.01	9.48	554.00	94,155.48
Water	2.71	2.80	411.93	12,676.61	1.27	66.84	13,162.16
Built-up land	0.36	0.00	1.26	0.00	89.58	0.00	91.20
Unused land	1.48	4.95	372.60	17.79	1.83	14,485.72	14,884.37
Total	1,250.85	7,757.01	94,366.20	12,825.94	110.04	15,109.96	131,420.00

Table 4 Land use transfer matrix from 2000 to 2005

Change in area (km^2) by 2005

2000	Farmland	Forest	Grassland	Water	Built-up land	Unused land	Total
Farmland	1,235.30	0.00	5.32	8.88	0.57	0.78	1,250.85
Forest	0.00	7,756.93	0.00	0.08	0.00	0.00	7,757.01
Grassland	27.36	21.36	94,132.72	122.69	3.90	58.17	94,366.20
Water	0.55	0.20	77.61	12,739.63	0.00	7.95	12,825.94
Built-up land	0.00	0.00	0.00	0.72	107.49	1.83	110.04
Unused land	1.83	0.00	68.08	66.79	0.00	14,973.26	15,109.96
Total	1,265.04	7,778.49	94,283.73	12,938.79	111.96	15,041.99	131,420.00

observed changes and resulted from two opposing processes. Natural or human disturbances (overgrazing, drainage of the swamps, etc.) converted forest, high-quality grassland, and swamp meadows into low-quality grassland, bare land, or sandy land (24.7% of the total change in area). On the other hand, natural succession or human(plantation) such as restoring farmland to forest or grassland, protecting native grassland from grazing, and planting shelter forests led to vegetation recovery (47.96% of the total change in area), leading to a transition from low-quality grassland, bare land, or sandy land to high-quality grassland, swamp meadow, or forest.

Anthropogenic land-use change processes include reclamation of land for agriculture and urbanization. As a result of the continuous population growth in the region, increasing amounts of grassland and swamp meadow were converted into farmland and rangeland. Many farmlands in the study area were abandoned after several years of cultivation, when the land's fertility was exhausted. Population growth also led many citizens to keep larger numbers of livestock. This produced unsustainable pressure on the rangeland over a long period, leading to the conversion of much high-grade rangeland into bare land or sandy land. Finally, urbanization represents an irreversible

change that converted grassland, farmland, and forest into residential areas with sealed soil surfaces.

Driving forces behind LUCC

Human activities and natural factors can influence LUCC at the regional landscape level. However, because of the relatively low population density and the corresponding weak intensity of human activities, natural factors were the dominant driving forces behind LUCC. In this study, we analyzed the driving forces in four major categories: climate, human activities, animal and insect damage, and political measures.

Climate

Climate change is a major factor in LUCC, and had two main aspects: temperature and precipitation. In this study, we used data from the Xinghai, Maqu, and Maduo meteorological stations to analyze trends in temperature and precipitation during the study period. We used a cubic polynomial regression model to simulate the trends in mean annual temperature and total precipitation during the study period (Fig. 3). The results showed (1) a significant increase in air temperature, by about 0.05°C per year in study area (Wang et al. 2001); (2) a decrease in precipitation from 1981 to 2000 in study area, with an especially

Fig. 3 Changes in mean annual temperature and total annual precipitation from 1980 to 2007 based on data from the Xinghai, Maduo, and Maqu meteorological stations
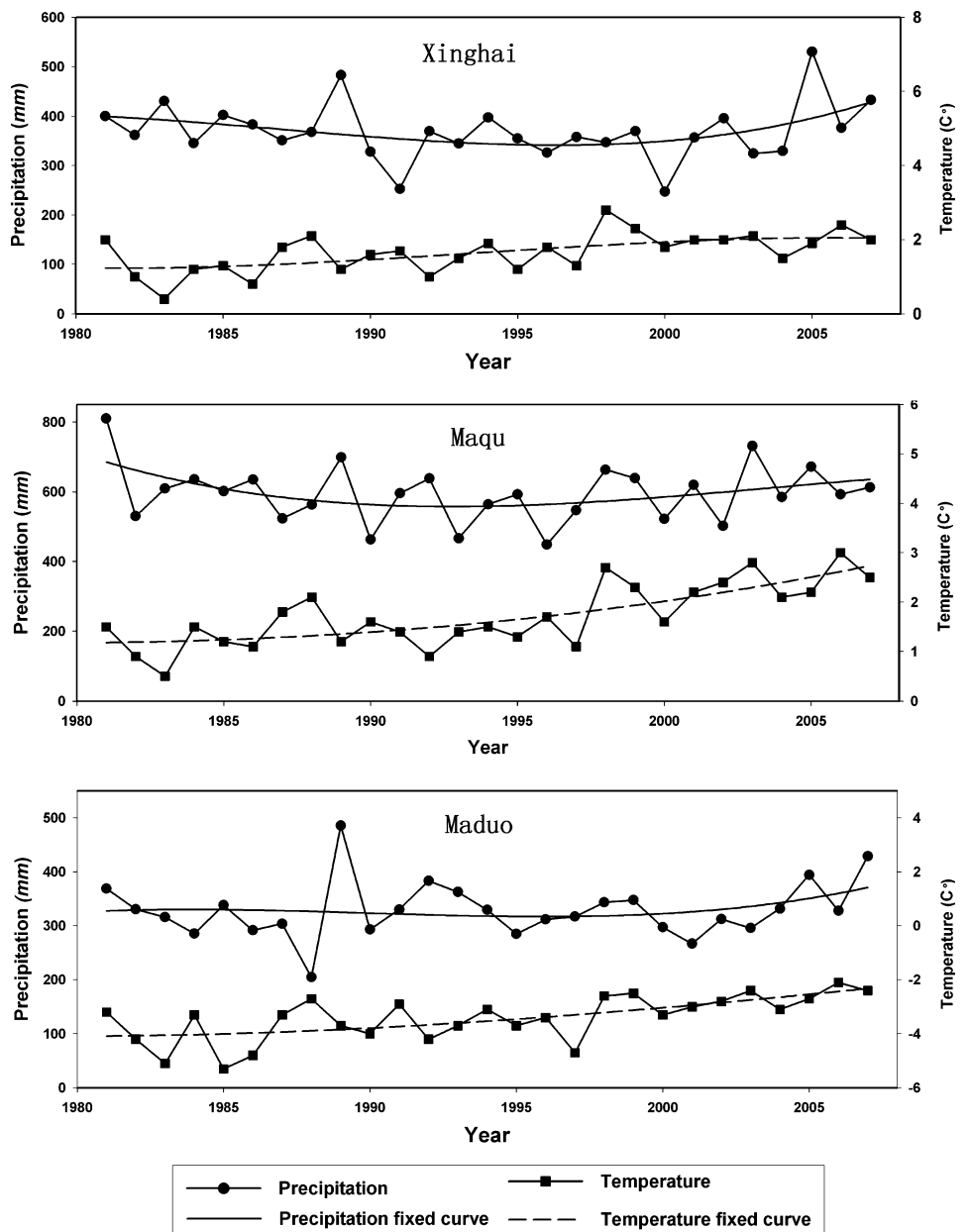
dry period that lasted five years in the mid-1990s and that accelerated desertification (Feng et al. 2004); and (3) increasing precipitation after 2000 in all three areas, accompanied by decreased desertification and by vegetation recovery.

These climatic changes also led to changes in the extent of permafrost and the hydrologic environment. Numerous studies (e.g., Ji 1996; Zhao 1996) have shown that during the past 30 years, the upper permafrost layers have warmed by an average of 0.2–0.3°C, leading to thawing of a large area of permafrost and even the disappearance of the permafrost in some areas. This, in turn, has decreased soil moisture in the root zone, and has led to desiccation of the soil surface, drying of swamps and lakes, and changes in soil structure and composition. Furthermore, these changes have led to degradation of the high cold meadow and swamp meadow vegetation, succession to different dominant plant species, and increased desertification in affected areas (Wang 1998; Cheng and Wang 1998; Wang and Cheng 1999).

Human activity

In the study region, farmland accounted for less than 1% of the total area, and cattle grazing on natural rangeland was the main economic activity. Although livestock populations fluctuated during the study period, they have generally increased since the 1950s, showing a nearly linear increase (Feng et al. 2006). Desertification resulting from overgrazing is widespread in the study area (Cheng 1998; Dong et al. 1998; Niu 1999). According to Wang et al. (2001), the actual carrying capacity greatly exceeded the theoretical carrying capacity (except in the warm-season rangeland of Maduo region), especially during the cold season. Their rate could reach to 0.25–0.76 (Table 5). In addition, grazing is unbalanced between the seasons. The cold-season (fall, winter, and spring) grazing area is generally smaller than the warm-season (summer) grazing area; the cold-season grazing area accounts for 40–50% of the total grazing area, but the cold-season grazing period is up to 240 days, roughly two times the length of the summer grazing period. As a result, serious overgrazing takes place

from October to May over a large part of the grassland in the study area (Wang and Cheng 2000).

As the region's population has grown, the impacts of human activity on the eco-environment have been exacerbated. Irrational reclamation of land for agriculture has caused deterioration of the eco-environment and degradation of natural vegetation. As a result of deforestation, the area of forest has declined, leading to a weaker water conservation function provided by the forest and to degradation of vegetation.

Animal and insect damage

Serious damage to vegetation by animals and insects has occurred in large areas of high cold meadow rangeland in the study region. Field investigations have shown that this damage was mainly caused by pikas (e.g., *Marmota sibirica*). Wang and Cheng (2000) reported that animal and insect damage caused losses of 2.4 billion kg of forage yield per year, corresponding to the food consumption of 4.8 million sheep. Animals and insects have severely damaged rangeland vegetation, altered the vegetation community composition, and turned areas of grassland into "black soil flats" as a result of burrowing. The burrows of pikas expose large areas of soil, creating breakthrough points where erosion begins, thereby accelerating desertification and the degradation of vegetation communities.

Political measures

Since 1998, a series of key national projects has been initiated to combat degradation of the eco-environment in the study area and northwestern China. The measures that have been taken include abandoning and revegetating farmland to produce forests or grassland, protecting native forests against deforestation, planting shelter forests, and taking steps to conserve both soil and water. These projects have slowed the rate of desertification, and led to obvious restoration of grasslands and forest vegetation, and the greater the annual precipitation in an area, the greater the improvement that has been observed. However, although

Table 5 Theoretical and actual carrying capacities of the rangeland in the study region

Region	Carrying capacity ($\times 10^4$ sheep units)			Distribution of cold/warm season rangeland (% of total area)
	Actual carrying capacity	Theoretical carrying capacity of cold-season rangeland	Theoretical carrying capacity of warm-season rangeland	
Maduo	87.5	66.7	304.89	43.08/56.92
Maqin	183.04	46.16	49.97	51.95/48.05
Qumalai	142.58	70.12	98.46	39.62/60.38

Source Wang et al. (2001)

many eco-environment conservation projects have been carried out, these projects have not improved the vegetation cover greatly because it is difficult to restore degraded vegetation communities in the study area due to the ecosystem's fragility (Yan et al. 2005).

Conclusions

LUCC occurred slowly during the study period. Overall, LUCC remained relatively stable. Grassland is the major land use and cover in the study region, accounting for nearly 72% of the total area throughout the study period. Different land use types have shown different trends; from 1989 to 2000, these changes were mainly reflected in degradation of swamp meadows and grassland as well as by desertification. These adverse changes were most prominent from the mid-1990s onward because of reduced precipitation during this period (Fig. 3). From 2000 onwards, improvement was the dominant trend, represented by increased sizes of rivers and lakes, restoration of vegetation, and slowing of the rate of desertification.

We found that the processes responsible for LUCC could be divided into natural and anthropogenic groups by analyzing the transition matrices. Climate change (an overall trend to a warmer and drier climate) appears to have been an important factor. Human activities and animal and insect damage also played important roles. The impact of political measures was also significant, particularly in terms of vegetation restoration.

Precipitation is the most important factor for vegetation growth. When precipitation increased, the trend towards desertification weakened and vegetation recovered, whereas decreased precipitation accelerated the desertification. Air temperatures in the study area have increased by 0.05°C per year. As a result, large areas of permafrost have thawed, and some permafrost has even disappeared. This has led to degradation of the high cold meadow and swamp meadow vegetation communities and desertification in some areas.

Livestock husbandry has also had important effects. The seasonal grazing is unbalanced, with the cold-season grazing area smaller than or similar to the warm-season grazing area, but exploited for nearly twice as many days per year, leading to unsustainable pressure on this resource. As a result, serious overgrazing takes place from October to May in a large part of the grassland, leading to grassland degradation. With rapid population growth, the impacts of human activity on the eco-environment have also been exacerbated. Animals and insects have also damaged the vegetation, and animal burrows have become breakthrough points for erosion, accelerating desertification in some areas.

Although some political measures could help to restore vegetation and slow desertification, such as key national projects to restore the ecological environment, the fragile nature of the region's ecosystem will make it difficult to rehabilitate the eco-environment.

References

Cheng G (1998) Some understandings about the eco-environmental protection and building in the source region of Yangtze and Yellow Rivers. Adv Earth Sci 13(Suppl):1–5

Cheng G, Wang G (1998) Eco-environmental degradation and causal analysis in the source region of the Yellow River and Changjiang River, Qinghai-Xizang Plateau. Adv Earth Sci 13(Suppl):24–31

Dong G, Yan P, Su ZH (1998) The urgency of research and control of land desertification in the source area of Yangtze and Yellow Rivers. Adv Earth Sci 13(Suppl):32–36

Feng JM, Wang T, Xie CW (2004) Land desertification in the source region of the Yellow River: Northeast Qinghai-Xizang Plateau. Ecol Environ 13(4):601–604

Feng JM, Wang T, Xie CW (2006) Eco-environmental degradation in the source region of the Yellow River, Northeast Qinghai-Xizang Plateau. Environ Monit Assess 122:125–143

GICAS (Geography Institute of Chinese Academy of Sciences) (1990) Atlas of Qinghai-Xizang Plateau. Science Press, Beijing, pp 77–79

Ji Z (1996) Periglacial wetland and its environment effect and ecological construction in China. Glaciol Geocryol 18(Suppl):274–280

Li XB (1996) A review of the international researches on land use/land cover change. Acta Geographica Sinica 51(06):553–558

Liu JY (1996) Macro-scale survey and dynamic study of natural resources and environment of China by remote sensing. China Science and Technology Press, Beijing, pp 113–124

Müller D, Zeller M (2002) Land use dynamics in the central highlands of Vietnam: a spatial model combining village survey data with satellite imagery interpretation. Agric Econ 27:333–354

Niu Y (1999) The study of environment in the Plateau of Qinghai-Tibet. Process Geogr 18(2):163–171

Pan BT, Li JJ (1996) Qinghai-Tibetan Plateau: a driver and amplifier of the global climatic change. J Lanzhou Univ (Nat Sci) 32(1):108–115

Runnstrom MC (2003) Rangeland development of the Mu Us sandy land in semiarid China: an analysis using Landsat and NOAA remote sensing data. Land Degrad Dev 14:189–202

Stefanov WL, Ramsey MS, Christensen PR (2001) Monitoring urban land cover change: an expert system approach to land covers classification of semiarid to arid urban centers. Remote Sens Environ 77:173–185

Steffen W, Jäger J, Carson D, Bradshaw C (eds) (2002) Challenges of a changing earth. Springer-Verlag, New York, pp 21–26

Vitousek PM, Fautin DG, Futuyama DJ, James FC (1992) Global environmental change: an introduction. Annu Rev Ecol Syst 23:1–14

Wang S (1998) Discussion on the permafrost degradation and the changes of the permafrost environment of Qinghai-Xizang Plateau. Adv Earth Sci 13(Suppl):65–73

Wang G, Cheng G (1999) The ecological features and significance of hydrology within arid inland river basins of China. Environ Geol 37(3):218–222

Wang GX, Cheng GD (2000) Eco-environmental changes and causative analysis in the source regions of the Yangtze and Yellow Rivers, China. Environmentalist 20:221–232

Wang GX, Shen YP, Cheng GD (2000) Eco-environmental changes and causal analysis in the source regions of the Yellow River. J Glaciol Geocryol 22(3):200–205

Wang G, Qian J, Cheng G, Lai Y (2001) Eco-environmental degradation and causal analysis in the source region of the Yellow River. Env Geol 40:884–890

Weng QH (2002) Land use change analysis in the Zhujiang Delta of China using satellite remote sensing, GIS and stochastic modelling. J Environ Manage 64:273–284

Wilson EH, Hurd JD, Civco DL, Prisloe MP, Arnold C (2003) Development of a geospatial model to quantify, describe and map urban growth. Remote Sens Environ 86:275–285

Yan CZ, Wang T, Guo J, Zhang Y (2005) Evaluating effects of national key eco-environment conservation projects by vegetation change on the Loess Plateau of China. Paper presented at the IEEE international geosciences & remote sensing symposium, Seoul, Korea, 25–29 July 2005

Zhao L (1996) Soil characteristics affected by permafrost. In: Annual report on comprehensive observation and study of Qinghai-Xizang Plateau. Lanzhou University Press, Lanzhou, pp 70–76

Zheng D, Li BY (1999) Progress in studies on geographical environments of Tibetan Plateau. Acta Geographica Sinica 19(4):295–302

Zhuang DF, Liu JY, Liu ML (1999) Research activities on land use/land cover in the past ten years in China using space technology. Chin Geogr Sci 9:330–334