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ORIGINAL ARTICLE

The ecological implications of land use change in the Source Regions of the Yangtze and Yellow Rivers, China

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Abstract The alpine ecosystems in permafrost regions are extremely sensitive to climate change. The headwater regions of Yangtze River and Yellow River of the Qinghai-Tibet Plateau are on the permafrost area. Aerial photos of the Source Regions of the Yangtze and Yellow River taken in 1968 and three phases of TM images acquired from 1986, 2000, and 2008 were used to analyze the spatial alterations of the land cover and corresponding effects on the environment guided by landscape ecology theory. Firstly, land cover types were divided into three classes and 11 subclasses. Analysis results revealed the trends and magnitude of the eco-environmental changes in the regions over the past four decades and showed a continuous degradation of grasslands and the extension of desertification and salinization. Secondly, five landscape pattern indices (i.e., NP, MPS, PR, SHEI, CONTAG) commonly used in landscape ecological studies were calculated, and results showed that this region had become more centralized and diversified. Finally, the factors causing the degradation of alpine grasslands were analyzed. The regional climate exhibited a tendency toward significant warming and desiccation with the air temperature increased by 0.03 °C per year and relative stable precipitation over the last 40 years. And the temperature of permafrost in 0–20 cm soil layer obviously raised by 0.2–0.3 °C in the last 40 years. The combined effects of climate warming and permafrost variation were the major drivers for the changes of landscape in alpine ecosystems.

Keywords Land cover · Temporal and spatial patterns · Grassland degradation · Source Regions of the Yangtze and Yellow Rivers · Qinghai-Tibetan Plateau

Introduction

With numerous large and small rivers, the Source Regions of Yangtze and Yellow Rivers are some of the densest river-distributed regions in the world. This regions are commonly known as "China's water tower," and the world's largest alpine meadow and swamp meadow with the highest altitude, in addition to being rich in biodiversity (Chen and Gou 2002; Dong et al. 2002). However, the natural alpine ecosystems and environments in the regions are inherently fragile and instable, making them especially vulnerable to global warming and human activities. In addition, some preliminary researches have shown that the alpine ecosystems had been seriously degraded (Cheng et al. 1998; Qian et al. 2006; Wang et al. 2001). Therefore, the regions had become the focus of public concern and had received considerable attention from scientists (Chen and Gou 2002; Dong et al. 2002; Wang and Cheng 2000).

Terrestrial ecosystems, with land type composition at the core, include various elements such as soil, vegetation, climate, and the relationships to land use. They can be classified by a combination of land cover and ecosystem types, possessing certain similarities with the classification of landscape ecological types. Land cover changes are vital

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important in regional, social, and economic development and environmental changes (Luciana et al. 2007; Turner et al. 1993). These changes can affect a variety of ecological processes, such as water runoff and erosion, as well as the spread of disturbance or boundary phenomena in general (Turner and Ruscher 1988). The fragmentation of natural habitats, including grasslands, is a serious conservation problem, although today it is a common ongoing process all over the world in agricultural and marginal areas because of changes in land use. Thus, in order to understand the landscape dynamics, changes in the spatial patterns of land cover overtime may be crucial. A thorough comprehension of the patterns, causes, and the social and ecological consequences of historical changes will enhance our capability to predict future landscape dynamics and devise more effective landscape management strategies (Kienast 1993). Landscape ecology has played an important role in studying regional eco-environmental problems, which were characterized by land degradation and vegetation succession (Forman 1995; Xiao 1999). Many methodologies and algorithms have been used to derive land cover change information from different kinds of remote sensing data. The satellite remote sensing technical and informational systems can provide systematical spatial data, and consequently make the quantification of the spatial variation in land surface characteristics and modern processes experience rapid development (Qian et al. 2006). Furthermore, these systems also make quantification studies possible, which are ways to analyze the driving factors that caused the eco-environmental change and design plans for the protection and construction of eco-environment (Shi et al. 2000; Long and Li 2001).

The primary studies analyzed two phases of remote sensing data in 1986 and 2000 in the Headwater Regions of the Yangtze and Yellow Rivers (Qian et al. 2006). The changes of landscape had already happened in 1986, but the developing treads of alpine ecosystems did not show clearly in 2000. Two phases of satellite data cannot show the accurate and objective changes in the Headwater Regions. This paper selected aerial photo in 1968 as the baseline and added another TM/ETM satellite image data in 2008, and it greatly extended the analysis of time series of remote sensing data, which made the discussions more accurate and objective. The aim of this study was to quantify the changes in land cover and differences in landscape development in the Headwater Regions of the Yangtze and Yellow Rivers over the period 1960s–2000s. With the aim of quantifying landscape patterns, we used a series of landscape pattern indices commonly used in landscape ecological studies (Forman and Godron 1986; O'Neill et al. 1988; Turner and Ruscher 1988). We endeavor to show that in spite of continued land degradation of this alpine ecosystem, small changes have a significant impact on landscape and vegetation patterns. The changes in land cover occurring here can be expressed as changes in the disturbance regime critical for the maintenance of natural habitats of alpine grasslands. Such factors are the abandonment of regional pastureland, global warming, and the uplifting of the permafrost layer (Olsson et al. 2000). The responses to these changes are visible as successional processes leading to ecosystem and landscape changes. We are using data on historical land cover elaborated in details by Wang et al. (2001), as well as landscape data from various generations of aerial photos and fields surveys.

Study area and methods

Study area

In this study, the Headwater Regions of the Yangtze and Yellow River were chosen as the study sites, which cover the area of 12.12×10^4 and 6.48×10^4 km^2, respectively. The headwaters are located in a transitional region of alpine semiarid climatic zones and are characterized by a mean annual temperature of −4.3 °C and a mean annual precipitation of 270–520 mm (Wang et al. 2004). Permafrost is well distributed in the headwater of the Yangtze River, with the depth averaging between 50 and 120 m, and in the headwater area of the Yellow River, permafrost was discontinuous and sporadic, with the depth below 50 m (Zhou et al. 2000). The main native alpine ecosystems in this region are alpine steppe, alpine meadow, and alpine swamp meadow (Wang et al. 2004). Alpine steppe ecosystems, consisting of hardy perennial xeric herbs and dwarf shrubs, are dominated by the species of *Stipa purpurea Grisebach steppe*, *Carex moorcroftii Falc. ex Boott. steppe,* and *Dalea racemosa steppe,* etc. Alpine meadow ecosystems consist mainly of cold mesophytic perennial herbs growing under moderate water stress conditions, where the soil is unsaturated. Alpine Meadow ecosystems are dominated by *Kobresia pygmaea* (C.B. Clarke) C. B. Clarke, *Kobresia humilis* (C. A. Mey.) *Serg., Kobresia tibetica*. Formed in areas with permanent waterlog or where the soil is saturated. The alpine swamp meadow ecosystems support hardy perennial hydrophilous or hydromesophytic herbs (Zhou 2001; Wang et al. 2004).

Based on the principles of landscape-ecotypes classification (Xiao et al. 1997), the characteristics of the land cover, and the interpretation of satellite and remote sensing images, the Regions could be categorized into eight landscape ecotypes: (a) alpine steppe (AS), (b) alpine meadow (AM), (c) alpine swamp meadow (ASM), (d) mobile and semi-fixed sandy lands (SAND lands), (e) saline-alkali land (SAL lands), (f) bare rock, soil and shoaly land (BRS andS lands), (g) river and lakes (Rivers and Lakes), and (h) glacier and permanent snow cover lands (GL andPS lands). Of these, there were three main alpine ecosystems: alpine steppe, alpine meadow, and alpine swamp meadow; these three types accounted for 70 % of the total headwater regions and are at the core of the evolution of the eco-environment in the regions.

Methods

Field investigations and remote sensing data were combined in this study. The dynamic data of temperature and precipitation over the past 50 years were collected from 4 meteorological stations in the Yangtze River Source Region and 3 meteorological stations in the Yellow River Source Region. The data of the surface layer of permafrost temperature from 1996 to 2005 were obtained from 5 field observations, namely Kunlun Mountains, Wudaoliang, Fenghuoshan, Danggula Mountains, and Chumaer Plain in the Yangtze and Yellow River Source Regions.

Based on the classification of land ecological types, the various features of alpine ecological changes in the study areas were described using one aerial photo from 1968, and three years (1986, 2000, and 2008) of Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) satellite image data. Through radiometric calibration and geometric rectification processing of the TM (ETM) images, and using Universal Transverse Mercator (UTM) geographic coordinates to rectify the images, and topographic maps (1:100,000) to make map-image rectification, the accuracy was Root Mean Square (RMS) ≤ 1 pixel. The images for interpretation were Red Green Blue (RGB) fusion, which were the standard 432 wave bands fusion. In addition, the images were enhanced by linear and square root enhancements. The resolution of the original Landsat TM/ETM data was 30 m × 30 m; the remote sensing analytical schemes for 26 subtypes were established (Fig. 1).

Based on the interpretation of remote sensing images and landscape types, the area was divided into three ecological landscape types: (1) alpine grasslands, which were subdivided into high-cover AM (covering >70 %), mid-cover AM (50–70 %), low-cover AM (<50 %), high-cover AS (>50 %), mid-cover AS (30–50 %), low-cover AS (<30 %), and ASM; (2) water bodies, including rivers, lakes, and glaciers; (3) barren lands, including sandy soils, saline-alkali soils, bare rock, and shoaly soils (Qian et al. 2006; Wang et al. 2003). These three landscape types represented the main eco-environment systems of the Source Regions of the Yangtze and Yellow Rivers, their spatial patterns, and changes that reflect the qualitative changes of the eco-environment in the area.

To analyze the alpine spatial pattern changes, two landscape indexes were used: The variation in extent of land cover attributable to a specific tundra type V_i and its rate of variation in time R_i were defined as (Wang et al. 2004):

$$V_i = \frac{(LU_{k_i t_1} - LU_{k_i t_0})}{LU_{k_i t_0}} \times 100\,\%$$

$$R_i = \frac{(LU_{k_i t_1} - LU_{k_i t_0})}{LU_{k_i t_0}} \times \frac{1}{T} \times 100\,\% = V_i \times \frac{1}{T}$$

where i subscript represents tundra ecosystem type, k subscript represents the sub-region, t_0, t_1 subscript represents time of onset and end, respectively, of the time interval, T, understudy, $LU_{k_i t_0}$ and $LU_{k_i t_1}$ represent the area of the i th tundra ecosystem in the k th subregion at the start and end of the study period, respectively.

Using FRAGSTATS (Table 1) (McGarigal and Marks 1994), another 5 landscape indices were chose to analyze the dynamic change characteristics of the total land cover in the Source Regions of the Yangtze and Yellow Rivers. Then, land spatial distribution patterns in the region were analyzed in two different ways. First, a comparative analysis of the changes in the spatial distributions of the eco-environmental variation features and ecosystem types over the past 40 years was conducted. Second, a straightforward study on the features of landscape pattern changes in the source areas was discovered by comparing the landscape spatial indices, landscape diversity, and heterogeneity indices for 1968, 1986, 2000, and 2008. Finally, based on the data of temperature, precipitation, and depth of frozen soil, analysis was then performed to analyze the causes for the degradation of the ecosystems.

Results and discussions

Changes in the spatial distribution of alpine ecosystems

Changes in the alpine grassland ecosystems

Landsat TM imagery is a synoptic, timely, and spectrally sensitive digital dataset that allows for landscape-level investigations of land cover change. In this study, we investigated the landscape changes of alpine ecosystems based on four different datasets. In general, great changes in eco-environment have taken place in the 18.6 × 10^4 km^2 area covered by the Source Regions of the Yangtze and Yellow River, in which grasslands were valuable for their numerous functions, including water conservation, biodiversity conservation, breeding habitat, and regional sustainable development. Figure 2 shows the continued degradation of AS, AM, and ASM ecosystems between 1968 and 2008. AS is the largest degraded landscape type in the Source Regions, and it has degraded rapidly, with the coverage area decreased by

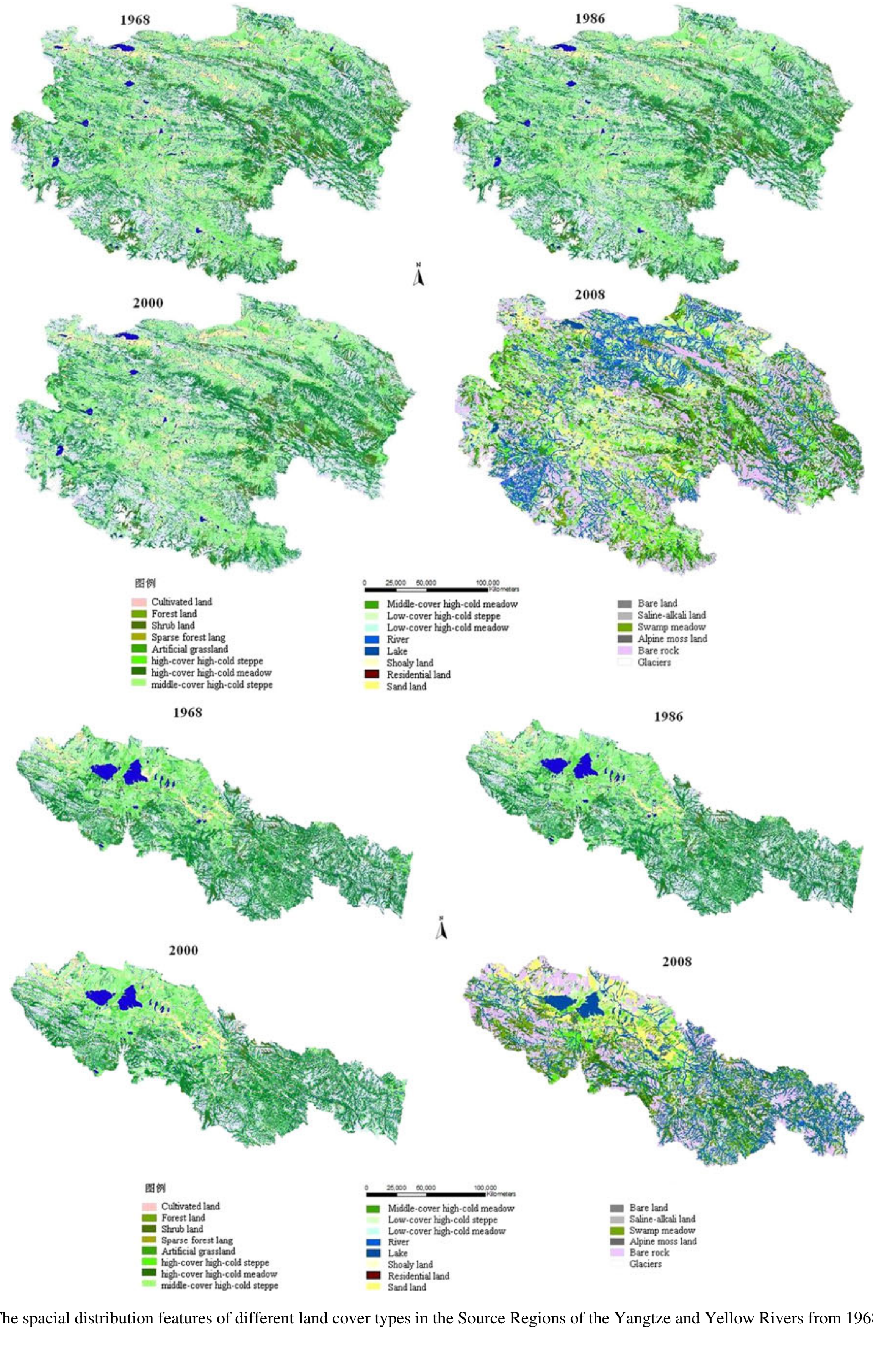

Fig. 1 The spacial distribution features of different land cover types in the Source Regions of the Yangtze and Yellow Rivers from 1968 to 2008

Table 1 Description of landscape ecologic indices

Indices	Definition	Units
Number of patches (NP)	Number of patches is a measure for the extent of subdivision or fragmentation of patch type	None
Mean patch size (MPS)	Patch size is a measure of the subdivision of class or landscape; mean patch size means that landscape shape is more regular	None
Patch richness (PR)	The patch richness describes the total number of different patch types	None
Shannon's evenness index (SHEI)	Shannon's evenness index measures the evenness of proportional distribution of patch type area	None
Contagion (CONTAG)	Contagion index describes the degree of contagion between the same patch type	None

6,558.4 km^2. This primarily occurred from 1986 to 2000, accounting for 62.67 % of the total decrease; The decreased rate was even faster in the Yellow River than in the Yangtze River Source Region, with a decreased rate of 38.11 versus 15.17 %. In the same period, AM also degraded extensively, it decreased by 557.3 and 1,231.19 km^2 in the Source Regions of Yangtze and Yellow Rivers, respectively, and then increased from 15,054.84 km^2 in 2000 to 15,301.92 km^2 in 2008 in Yangtze River Source Region and from 13,472.63 km^2 in 2000 to 13,685.66 km^2 in 2008 in Yellow River Source Region. Since AS and AM in the Yellow River Source Region were subjected to high grazing stress and thus degraded more severely than in that of the Yangtze River, while ASM showed more sensitive to climate changes, it degraded more severely in the Yangtze River Source Region. The ASM decreased by 3,177.59 km^2 during 1968–2008, and roughly 96 % of the loss took place between 1986 and 2000; it decreased by 2,645.18 and 532.41 km^2 in the Source Regions of Yangtze and Yellow Rivers, respectively (Fig. 2).

The long-term maintenance of the alpine grasslands has ensured the development of specific plant communities of high species diversity and a mixture of alpine species (Wang et al. 2001). One of the few endemic species, *Kobresia tibetica*, is a montane grassland species that occurs in the alpine grasslands. Another feature of the grasslands here is that a variety of alpine plant species are vulnerable in the world context, such as *Cordyceps sinensis*, which is a grassland fungus. With climate warming continuing and human's unreasonable use of pasture that has led to habitat destruction, high-cover grassland landscape, with high biological productivity, was degraded in both the Source Regions, whereas the area of low-cover grassland increased significantly from 1968 to 2008 (Fig. 2; Table 2). The area of low-cover AS increased by 12.82 % in the Yangtze River's Source Region and 53.33 % in the Yellow River's Source Region. Due to the grassland degradation, *Cordyceps sinensis* was once relatively widespread in the study region but are now almost extinct or seriously reduced in population size in the Source Region on the Qinghai-Tibetan Plateau and in China. We still find remnants of this vegetation type in some enclosures in the Yellow River Source Region, but

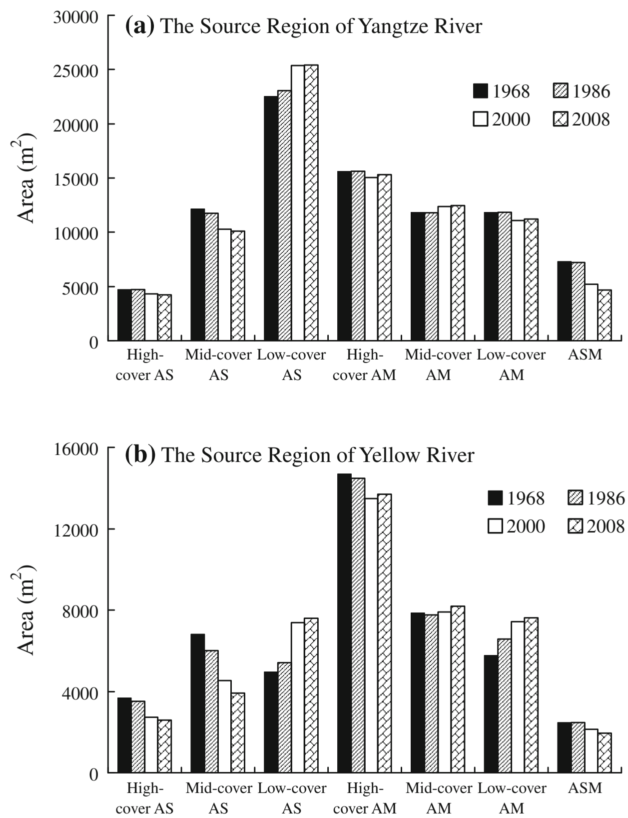

Fig. 2 Changes in the typical alpine grasslands area in the Source Regions of the Yangtze River (**a**) and Yellow River (**b**) of the Qinghai-Tibet Plateau

with global warming continuing, the grassland degradation will continue, which means that the alpine grasslands and heathlands will disintegrate and subsequently disappear— a process that will include a variety of extinctions and a decrease in biological diversity. The area of mid-cover AM grasslands increased by 950.67 km^2. Low-cover AM showed the opposite trend in the two rivers Source Regions: it increased by 31.77 % in the Yellow River Source Region, whereas decreased by 5.34 % in the Yangtze River Source Region, and the majority of the increase or decrease occurred from 1986 to 2000 (Fig. 2). Fortunately, the country had established a massive ecological rehabilitation programs in upper reaches of Yangtze and Yellow Rivers over the past decade, that is, Sloping Land Conversion Program, the ecological conditions might not necessarily have been degraded as have thought in the future.

Changes of water bodies and barren ecosystems

The lakes distributed mainly in the Yellow River Source Region, accounting for 59.06 % of the total lake area in the headwater regions, but the area covered by rivers was larger in the Yangtze River's Source Region, accounting for 69.29 % of the total area of the headwater regions (Fig. 3). Since 1968, the area covered by rivers and lakes has been continuously shrinking, the area shrunk by 301.01 km^2, accounting for 11.33 % of total lake area. Lake shrinkage mainly occurred in the Yellow River's Source Region, accounting for 9.84 % of the total lake area in the Yellow River's Source Region. The area covered by lakes in the Source Region of the Yangtze River decreased by 13.47 % (Table 3). The area covered by rivers decreased by 5.80 % of the total area, and the decrease mainly occurred in the Yellow River's Source Region, accounting for 81.65 % of the total decrease. Therefore, many wadis formed in the Yellow River's Source Region. Since the early 1980s, runoff measured at representative hydrological stations in the Yellow River Source Region has been decreasing continuously. Compared to the discharge in the early 1980s, the discharge has been showing a decrease of 19.3 % since 1995 (Qian et al. 2006).

Glaciers in the headwater regions covered 1,557.65 km^2 in 1968, 90.28 % of which was in the Yangtze River Source Region. From 1968 to 2008, the area covered by glaciers decreased by 43.93 % in the Yellow River Source Region. In the Yangtze River Source Region, the glaciers area decreased from 1,406.19 to 1,136.32 km^2. Meanwhile, the decrease was significant from 1986 to 2000, accounting for 88.33 and 86.44 % of the total decrease in the Yangtze and Yellow River Source Region, respectively (Fig. 3).

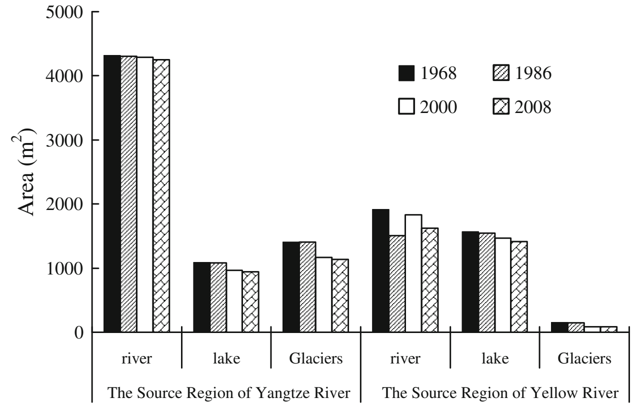

Fig. 3 Changes in area of lakes, rivers, and glaciers in the Source Regions of Yangtze and Yellow River of the Qinghai-Tibet Plateau

The changes of the distribution of the barren landscape types directly reflected the eco-environmental functions and evolutionary trends. In sum, barren landscape types in the headwater regions increased rapidly over the last 32 years (Table 4). In particular, land desertification in the Yellow River Source Region expanded very quickly, by 149.34 % during 1968–2008, with an expansion rate of 3.73 per year. The expansion rates of land desertification were 10.67 % in the Source Regions of the Yangtze River Source Region, which were significantly higher than those in the Hexi corridor (Wang and Cheng 2000). The increase in sandy landscapes mainly occurred from 1986 to 2000, which accounted for 88.65 and 63.83 % of the increase in the Yangtze and Yellow River Source Regions, respectively. SAL lands mainly distributed in the Source Region of Yangtze River, accounting for 95.78 % of the total area classified as barren landscape in the headwater regions. Its increase rate was higher in the Source Region of Yangtze River, at 1.81 km^2 per year. In the Source Region of Yellow River, the area of SAL lands increased by 149.35 %. With a total cover of less than 5 %, the BRS and S lands were the third landscape pattern only to AM and

Table 2 Changes in spatial distribution characteristics of AS, AM, and ACS ecosystems in the Source Regions of Yangtze River and Yellow River of the Qinghai-Tibet Plateau

Regions	Index	High-cover AS		Mid-cover AS		Low-cover AS		High-cover AM		Mid-cover AM		Low-cover AM		ASM	
		V_i	R_i	V_i	R_i	V_i	R_i	V_i	R_i	V_i	R_i	V_i	R_i	V_i	R_i
The Source Region of Yangtze River	1968–1986	−0.28	−0.02	−3.38	−0.19	2.36	0.13	0	0.00	−0.51	−0.03	0.11	0.01	−1.05	−0.06
	1986–2000	−8.35	−0.60	−12.48	−0.89	9.95	0.71	−3.57	−0.26	5.13	0.37	−6.65	−0.48	−28.11	−2.01
	2000–2008	−2.43	−0.30	−1.68	−0.21	0.25	0.03	1.64	0.21	0.56	0.07	1.29	0.16	−10.37	−1.30
	1968–2008	−10.83	−0.27	−16.86	−0.42	12.82	0.32	−1.99	−0.05	5.18	0.13	−5.34	−0.13	−36.24	−0.91
The Source Region of Yellow River	1968–1986	−4.7	−0.26	−11.8	−0.66	9.4	0.52	−1.6	−0.09	−1.1	−0.06	13.8	0.77	−0.2	−0.01
	1986–2000	−21.86	−1.56	−24.7	−1.76	36.27	2.59	−6.92	−0.49	1.88	0.13	13.16	0.94	−13.41	−0.96
	2000–2008	−5.67	−0.71	−13.63	−1.70	2.85	0.36	1.58	0.20	3.46	0.43	2.32	0.29	−9.18	−1.15
	1968–2008	−29.77	−0.74	−42.61	−1.07	53.33	1.33	−6.92	−0.17	4.30	0.11	31.77	0.79	−21.49	−0.54

Table 3 Changes in spatial distribution characteristics of lakes, rivers, and glaciers in the Source Regions of Yangtze River and Yellow River of the Qinghai-Tibet Plateau

Regions	Index	V_i			R_i		
		River	Lake	Glaciers	River	Lake	Glaciers
The Source Region of Yangtze River	1968–1986	−0.4	−0.80	−0.10	−0.02	−0.05	0.00
	1986–2000	−0.33	−10.64	−16.97	−1.51	−0.76	−1.21
	2000–2008	−0.84	−2.37	−2.59	2.68	−0.30	−0.32
	1968–2008	−1.53	−13.47	−19.19	−0.29	−0.34	−0.48
The Source Region of Yellow River	1968–1986	−21.10	−1.4	−4.40	−0.86	−0.08	−0.24
	1986–2000	21.45	−5.28	−39.72	1.53	−0.38	−2.84
	2000–2008	−11.69	−3.43	−2.70	−1.46	−0.43	−0.34
	1968–2008	−15.41	−9.84	−43.93	−0.39	−0.25	−1.10

AS. From 1968 to 2008, the area of barren landscapes increased by 3,274.59 km^2 and mainly occurred in the Source Region of Yangtze River, which increased 2,692.52 km^2 (Table 5).

Measures of the changes in landscape patterns

The landscape indices could be used to analyze changing conditions of the patches and predict the changing tendencies of land cover during 1968–2008 (Guan et al. 2008). The different indices used in this study were developed and applied mainly to large-scale landscapes (Hulshoff 1995; O'Neill et al. 1988). By comparing the index values for the two regions over the four stages, the differences between them can be illustrated. The indices shown in Table 6 reflected the tendencies of the landscape changes over four stages: NP decreased, and PR increased, the characteristic diversity values SHEI increased, and the CONTAG index increased. The features of ecological change can be analyzed: (1) the landscape tended to have a centralized distribution in both the Source Regions of the Yangtze and Yellow River, which was manifested in the NP decrease and MPS and CONTAG increases. Because of the poor connectivity of the dominant landscape patches, different landscape types exhibited an alternately aggregated distribution mode. (2) Landscapes tended to diversify and a balanced developmental tendency of various landscape patches. Because SHEI was negatively correlated to superiority, the increase in SHEI resulted in a decrease in superiority and suggested that the dominant landscape type in the studied area would be gradually lost, indicating a high evenness in the sizes of the different habitat categories. Consequently, the original landscape dominated by alpine meadow and alpine steppe maybe disappears. The above processes showed a degradation of the eco-environment in the Source Regions. (3) The PR index increased, which means new landscape patterns appeared in the Source Regions of the Yangtze and Yellow River, such as residential areas, cultivated land, and agricultural land. In general, the landscape in the Source Regions tended to have a centralized distribution in the Source Regions of the Yangtze and Yellow River.

The influencing factors for the changes in landscape patterns

Over the last forty years, the air temperature has been increasing since 1961 in the Source Regions, and its mean air increase was 0.03 °C per year (Fig. 4a). From 1981 to 2005, dramatic changes in air temperature took place in both the Source Regions of the Yangtze River and Yellow River, so that the air temperature had increased by 1.60 and 1.20 °C in these two regions by the year of 2005, respectively. Over the last 43 years, the annual precipitation in the Source Regions was almost the same, or remained stable (Fig. 4b), and the rate of increase was 0.362 and

Table 4 The area changes of unavailable land types in the Source Regions of Yangtze and Yellow river in 1968, 1986, 2000, and 2008/km^2

Region	The Source Region of Yangtze River			The Source Region of Yellow River		
Index	SAND lands	SAL lands	BRS&S lands	SAND lands	SAL lands	BRS&S lands
1968	2,990.27	138.35	25,231.87	1,530.87	6.1	12,458.73
1986	2,956.68	139.37	25,305.87	1,565.68	6.48	12,522.77
2000	3,328.03	142.46	27,634.76	1,968.09	13.39	13,006.91
2008	3,409.17	146.95	27,924.39	2,361.33	15.21	13,040.8

Table 5 Changes in spatial distribution characteristics of unavailable land types in the Source Regions of Yangtze and Yellow River of the Qinghai-Tibet Plateau

Regions	Index	V_i			R_i		
		SAND lands	SAL lands	BRS&S lands	SAND lands	SAL lands	BRS&S lands
The Source Region of Yangtze River	1968–1986	−1.1	0.7	0.3	−0.06	0.04	0.02
	1986–2000	12.56	2.22	9.20	0.07	0.16	0.66
	2000–2008	2.44	3.15	1.05	0.09	0.39	0.13
	1968–2008	14.01	6.22	10.67	0.01	0.16	0.27
The Source Region of Yellow River	1968–1986	0.9	2.3	6.2	0.11	0.13	0.35
	1986–2000	0.70	25.70	106.64	0.04	1.84	7.62
	2000–2008	0.40	19.98	13.59	0.48	2.50	1.70
	1968–2008	2.03	54.25	149.34	0.01	1.36	3.73

Table 6 Landscape index analysis of total landscape in the Source Regions of the Yangtze and Yellow Rivers

Region	Years	NP	MPS	PR	SHEI	CONTAG
The Source Region of Yangtze River	1968	21,285	5.69	18	0.7409	30.6421
	1986	20,436	5.93	19	0.7494	31.1943
	2000	18,698	6.48	20	0.7592	33.6360
	2008	17,180	7.05	21	0.7839	33.9612
The Source Region of Yellow River	1968	11,862	5.38	21	0.7025	33.1984
	1986	11,530	5.54	22	0.7190	34.0475
	2000	11,067	5.77	23	0.7359	35.6252
	2008	9,957	6.41	26	0.7483	37.5734

0.0667 mm/a in the Regions of Yangtze River and Yellow River, respectively. Therefore, the climate in the Source Regions of the Yangtze and Yellow River were characterized by a continuous rise in temperature without noticeable precipitation changes. Such climatic changes seriously affected the region's vegetation. During vigorous growth periods, that is, at the peak period for water requirements, the region's climate exhibited a tendency of drought, and thus, the normal growth and production of alpine grassland were seriously affected (Li and Zhou 1998; Wang et al. 2001).

Even more important, the climate warming caused significant changes in the permafrost layer in the study areas, and the temperature of permafrost in the upper soil layer (0–20 cm) on the Qinghai-Tibet Plateau had obviously risen by 0.2–0.3 °C in the last 30–40 years (Fig. 5). Since the Source Regions of the Yangtze and Yellow River are located in the permafrost zone, the presence of the permafrost layer plays a vital important role in the growth and production of alpine soil and vegetation. For example, various nutrients can be leached from the active layer and then concentrated in the permafrost layer. On the other hand, the permafrost layer can effectively prevent surface and soil water from seeping downward, holding higher water content in the root zone (Feng et al. 2006). In addition, lower soil temperature promoted the accumulation of soil organic matter (Ji 1996; Zhao 1996). The increased temperatures led to thawing of soil area, a thickening of the seasonal thawing layer, and finally, the entire permafrost layer may disappear (Wang 1998; Zhao 1996). The thawing of the permafrost led to soil moisture decrease, swamps drying up, surface soil desiccation, changes in soil structure and composition (Ji 1996; Zhao 1996), and finally may cause the decrease of soil nutrients. Furthermore, it may lead to the degradation of alpine grassland vegetation and initiate the succession of dominant plant species (Cheng et al. 1998; Feng et al. 2006; Wang 1998; Wang et al. 2009).

Natural climate conditions, permafrost, and human activities may be the three major factors that influence the changes of alpine ecosystems. According to investigation in the study region, the density of population is only 2.1 people per km^2, so the activity in the study region mainly manifests in the livestock grazing activities (Wang et al. 2001). The contribution of nature factor including climate and permafrost changes to the alpine grassland ecosystems degradation reached to 82–86 % in the headwater area of the Yangtze River (Wang et al. 2009). Therefore, compared to the effects of climate change, the grazing might have much weaker impact on the alpine grassland ecosystem.

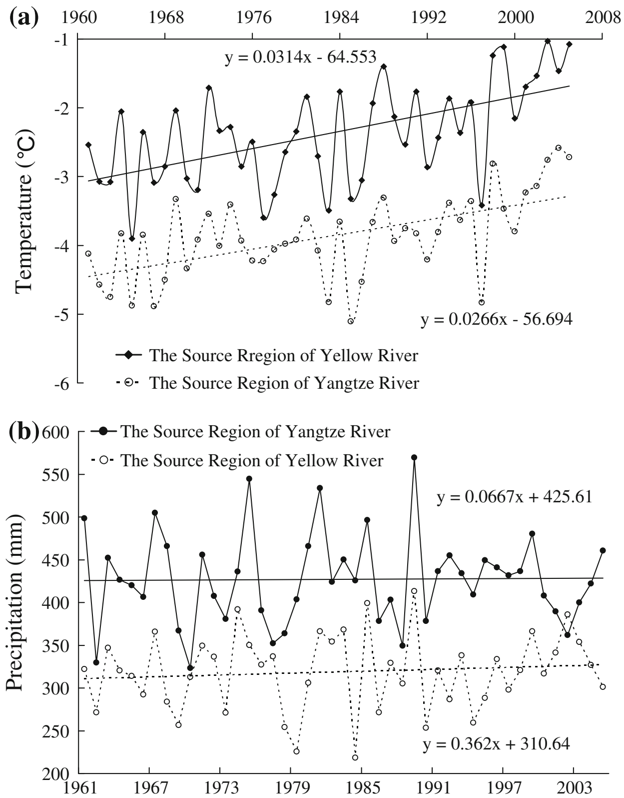

Fig. 4 Changes in temperature and precipitation in the Source Regions of the Yangtze and Yellow Rivers

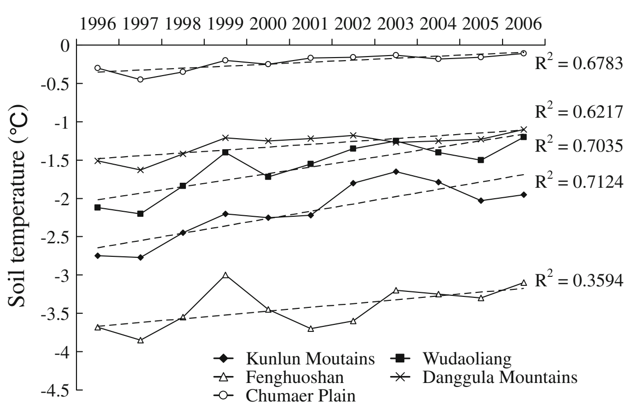

Fig. 5 Changes in the ground temperature of the permafrost layer in the Source Regions of the Yangtze and Yellow Rivers

Conclusions

In the permafrost region of the headwater Regions of Yangtze and Yellow River, the changes in air temperature, land cover, including changed ecosystems, grazing pressure, abandonment of pasture, as well as the onset of plowing in some areas, are all examples of changes in the disturbance regime of the alpine grasslands in this region. This resulted in the initiation of successional processes and subsequently to changes in habitat distribution, habitat areas, and transitions, from one habitat to another, and thus changes in the ecological content of the habitats (Olsson et al. 2000). Because of a decrease in patch sizes and the splitting of existing patches, the overgrowth of the low-cover grasslands and barren habitats, led to the fragmentation of those specific habitats. Further, with the changed land use, including the abandonment of grazing in the winter, and elevated temperatures during the growing season, the patch dynamics, resulting from the large diversity in land use, is about to disappear, and a more homogenous landscape can be expected.

Populations of endangered plant species will be especially vulnerable to the fragmentation of the alpine grasslands because it will include reduced fragment sizes and increased distances to sites with similar habitats; thus, isolation will be increased (Van Dorp et al. 1997). This phenomenon is particularly evident in the Source Regions where the remaining grasslands that are in enclosures appear like islands in a matrix of successional barren land. This is a significant difference compared to the situation about 40 years ago, when the alpine grasslands formed a network and sometimes continuous tracts in this region. Species with short life cycles are expected to experience larger fluctuations in the number of individuals, and for small populations in shrinking habitats, this combination could be hazardous (Fischer and Stöcklin 1997). Further, it must be considered that the present landscape patterns and the changed ecological content are a new one—at least in the last 1,000 years. There is a general lack of knowledge, and no measures of the stability of the current plant populations undercurrent conditions, because this situation is new in the majority of the populations (Mcintyre 1994).

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