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Ecological Degradation and Driving Forces in the Source Region of the Yellow River, China

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ABSTRACT

The source region of the Yellow River, located in the northeastern part of the Qinghai-Tibetan Plateau, is the typical environmentally fragile region of Chinese eco-environment. As the important water source supplying area of Yellow River, the source region is known as "plateau's water tower". There inhabit large quantities of rare wild animals. In this study, based on land ecological classification and field investigation, we used landsat images obtained in 2000 and 2015 to establish databases. From spatial distribution pattern variations and type transformation trend, the spatial changes and dynamic transfers of landscape ecotypes in the source region were analysed by using the analytical methods of landscape ecological spatial patterns. Results show that the unique natural conditions of the source region are more harsh and fragile. There have been phenomena of grasslands deterioration, desertification and wetlands shrinking, and water yield in the upper reaches of the Yellow River has been decreasing in recent years. In the source region, the serious eco-environmental problems have been caused by climate changes, rodent damages and human activities.

INTRODUCTION

The Yellow River, the second biggest river in China, is called "the cradle of Chinese nation". The source region of the Yellow River is located in the northeastern part of the Qinghai-Tibetan Plateau. Countless rivers and creeks originate in the source region of the Yellow River, where it is praised as "plateau's water tower". The source region was paid a close attention by the whole society, especially by the science researchers in recent years, because of its unique natural conditions, peculiar ecological functions, abundant natural resources, diversified biological species, and the great environmental impacts on the river basin (Cheng & Guo 2002).

The source region of the Yellow River is the typical environmentally fragile regions of Chinese eco-environment. With the global warming and human interference phenomenon getting worse and worse, the primitive landscape and ecosystem were destroyed in some degree (Wang et al. 2001). Thus, a series of eco-environmental problems appeared, such as desertification, grassland degradation, reduced runoff into rivers and increased soil erosion. As a part of the whole river basin, ecological degradation in the source region unavoidably made a great impact on the middle and lower reaches of the Yellow River (Xu et al. 2002). It is extremely urgent to analyse the main driving forces of ecological degradation in the source region and take scientific measures to protect and improve the eco-environment so as to maintain the ecological balance.

STUDY AREA

Our study focused on the source region of the Yellow River, between 33°30'-35°25'N and 96°00'-99°85'E, with an area approximately 6.48×10^4 km^2 (Fig. 1). The mean elevation is from 3,450 m to 6,621 m. The source region, which is high in the west and low in the east, has relatively low mountains, numerous lakes, and wide valleys. The source region is a typical continental alpine climate, characterized by cold and dry weather, sharp difference in temperature, much wind and snow, and violent climate changes. The annual mean air temperature is -4.3°C, annual mean precipitation is 540-350 mm, and annual mean evaporation is 1,240-1,328 mm (Wang et al. 2003). Because of the abundant biological species, the source region is praised as "the resources bank of biological species". There are various wild plants, including more than one hundred kinds of wild Chinese medical herbs, such as *Glycyrrhiza uralensis*, *Cordyceps sinensis*, *Rheum palmatum*, *Przewalskia tangutica*, *Gentiana straminea*, *Saussurea medusa*, etc. The wild animal resources are rich, most of which are peculiar alpine species, such as *Equus hemionus*, *Bos grunniens*, *Pantholops hodgsoni*, *Pseudois nayaur*, *Procapra picticaudata*, *Cervus albirostris*, *Panthera uncia*, etc. Soil in the source region is dominated by alpine cold meadow soil, as well as some alpine cold swamp meadow soils, which are common, but limit to small areas. Permafrost in the source region is quite well developed and has formed extensively distributed permafrost landforms such as frost mounds, melted mud-flow

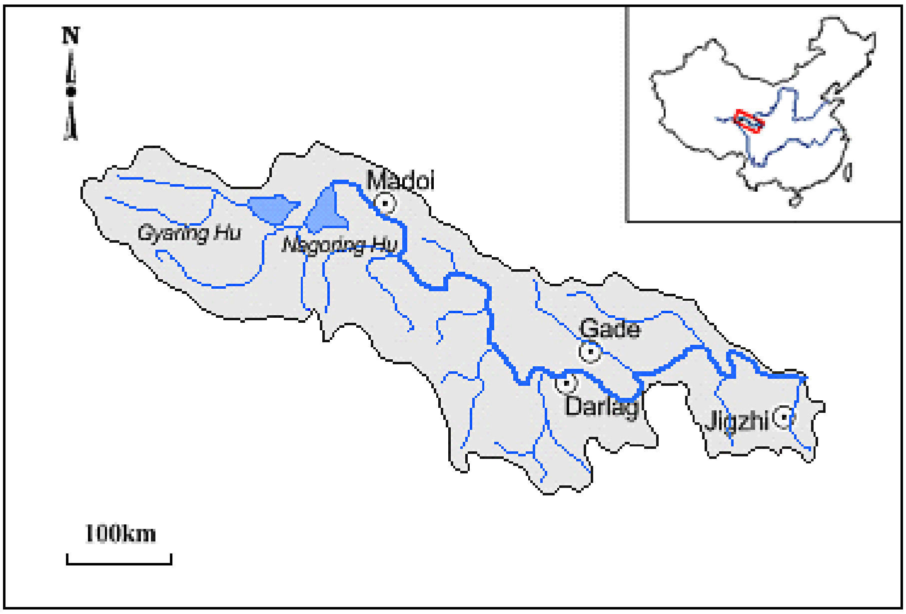

Fig. 1: Geographic location of study area in China.

terraces, and sliding and thermokarst lakes.

MATERIALS AND METHODS

Data sources: In this study, we used Landsat images obtained in 2000 and 2015 to establish databases of ecological system. The accurate geometric correction was the precondition of carrying out the compound analysis of the remote sensing images from different times and the remote sensing dynamic survey. We have processed the satellite images by radiated mark and geometric correction, adopted the UTM geographic coordinates to rectify images, and used the topographic map with a scale of 1:100,000 for image-to- image rectification. The RMS examination result shows that the mean location error for this rectification was less than 1 pixel (i.e., < 30 m). We acquired the standard false colour composite images of 432 wave bands by adopting the RGB colour composite project. At the same time, we had the colour enhancement processing to the primitive TM/ETM image, including the linear drawing and the colour composition. The resolution ratio of the TM/ETM primitive data was 30×30 m. With the assistance of field investigation, we established the remote sensing image interpretation marking-database that has 14 types and 246 marking points, and with the grassland ecosystem as the core, worked out a project of the remote sensing data analysis of 8 types and 35 second types and got the conclusion of soil type distribution in the source region of the Yellow River in 2000-2015.

We utilized the software system of ARC/INFO and ARC-VIEW to process the digital graphic, and adopted the methods of the landscape ecological patterns to analyse the spatial changes and dynamic transfers characteristics of the landscape ecotypes from two aspects. The first is to analyse the spatial changes of landscape ecotypes and to show the characteristics of eco-environmental changes in the region in 2000-2015. The second is to use the transfer probability random models and to show the transfer direction and extent of various land ecotypes in the source region of the Yellow River in 2000-2015 with the help of the transition matrices.

We used an area-weighted average method, analysed the general changes in vegetative cover caused by evolving landscapes in the area. Let the area of the landscape type i be Fi, the total coverage of landscape i be λi, and the regional area be A, the total vegetation cover at the end of time interval t is:

$$RC_t = \frac{1}{A}\sum_{j=1}^{n} F_{it}\lambda_i \quad ...(1)$$

The general changes in vegetation cover over any time interval can be calculated as:

$$\Delta RC_t = \frac{1}{A}\left(\sum_{j=1}^{n} F_{it-1}\lambda_i - \sum_{j=1}^{n} F_{it}\lambda_i\right) \quad ...(2)$$

Ecological system classification: The ecological system in the source region of the Yellow River belongs to the Qinghai-Tibet Plateau alpine arid zone. By regional ecological district division, it belongs to Qiangtang grassland

and desert ecological district of the semi-humid and semi-arid cold plateau ecosystem. The alpine cold and dry are the basic climate characteristics of the regional ecosystem, shaping its peculiar ecosystem structure thereby (Dong et al. 2002).

According to the land ecosystem division (Gai et al. 1999), the land ecosystem in the study area can be divided into the grassland ecosystem, including alpine cold meadow (ACM), alpine cold steppe (ACST), alpine cold shrub (ACSH), and alpine cold swamp (ACSW), etc.; the forest ecosystem composed of timberland (*Picea crassifolia*), sparse timberland (*Sabina przewalskii*), and a small amount of shrub timberland; the water area system composed of glaciers and permanent snows, lakes, rivers, etc., and the other hard utilizing land system, including sandy land, salt lick, bottomland, as well as bare rock and bare land (BR&L). Among them, grassland ecosystem account for 70.38% of the ecosystem present in the source region of the Yellow River. Its structure, functions and material circulation are the core of ecosystem evolution in this area. Therefore, grassland ecology is the core of eco-environmental problems research in the source region of the Yellow River. In grassland ecosystem, ACST and ACM are largest in area, composing the dominant part of the eco-environment, and the main carrier of grassland animal husbandry in this area. Alpine cold swamp meadow (ACSM) is an important ecotype in water-conservation and maintenance of biological diversity.

In order to explain the changing characteristics of the grassland ecosystem, based on the ecological division mentioned above, the main kind of grassland, such as the ACM and the ACST can be further divided into 3 kinds according to the different vegetative cover. They are the high vegetative cover ACST (the vegetative cover is over 50%), the middle vegetative cover ACST (the vegetative cover is 30-50%), and the low cover degree ACST (the vegetative cover is under 30%). As for the alpine cold meadow, they are the high vegetative cover ACM (the vegetative cover is over 70%), the middle vegetative cover ACM (the vegetative cover is 50-70%), and the low cover degree ACM (the vegetative cover is under 50%).

ECOLOGICAL DEGRADATION

Spatial changes of grassland: From Table 1, we can see that the ACST was severely degraded in the source region of the Yellow River in 2000-2015 by the comparative analysis of the remote sensing satellite data. The distribution area of ACST whose vegetative cover was more than 30% was principally degraded. Its area decreased by 2,250.09 km^2 and its extent decreased by 23.65%. The areas of the high vegetative cover ACM decreased by 1,001.20 km^2. Its extent decreased by 6.85%. On the contrary, the distribution area of ACST whose vegetative cover was less than 30% expanded significantly. The area increased by 1,964.97 km^2. Its extent increased by 36.27%. The areas of the low vegetative cover ACM increased by 846.85 km^2. Its extent increased by 13.16%. The area of the middle cover degree ACM increased slightly. Its extent increased by 1.88%. The changes of ACSM were very sensitive to environmental interference, and the distribution area of ACSM decreased by 331.59 km^2 in 2000-2015. Its extent decreased by 13.41%. The results show that the high vegetative ACST degraded severely. The area of the low cover degree ACST expanded notably. The changes of ACSM, that was sensitive to the climate change, were larger.

Spatial changes of water area system: As shown in Fig. 2, the glaciers and permanent snows were degenerating in the source region of the Yellow River by comparative analysis of the remote sensing satellite data in 2000-2015. The area of glaciers has decreased by 17.24%. The water area of lakes decreased by 81.79 km^2, and the extent decreased by 5.28% The outflow lakes decreased by 71.5%, and the inland lakes

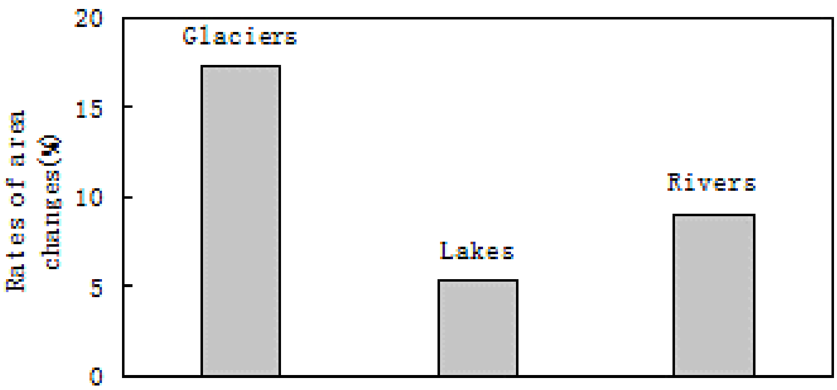

Fig. 2: The area changes of glaciers, lakes and rivers ecotypes in 2000-2015.

Table 1: The area changes of grassland types from 2000 to 2015 (unit: km^2).

Time and variety extent	Grassland Types					
	High-middle CST	Low ACST	High ACM	Middle ACM	Low ACM	ACSM
2000	9513.03	5417.74	14473.83	7766.22	6571.94	2473.29
2015	7362.92	7382.71	13472.63	7912.19	7436.49	2141.7
Rate of change (%)	-23.65	36.27	-6.85	1.88	13.16	-13.41

*alpine cold meadow (ACM), alpine cold steppe (ACST), alpine cold swamp meadow (ACSM).

Table 2: The area changes of unavailable land types from 2000 to 2015 (unit: km^2).

Time and variety extent	Grassland Types		
	Sandy land	Salt lick	BR&L, Bottomland
2000	1,565.68	6.48	12,522.77
2015	1,968.09	13.39	13,006.91
Rate of change (%)	25.65	106.63	3.95

Table 3: Transition matrices for grassland types from 2000 to 2015 in the source region (%).

2015	2000a									
	High ACST	High ACM	Middle ACST	Middle ACM	Low ACST	Low ACM	ACSM	BR&L	River	Sandy land
High ACST	72	0	8	0	15	0	0	3	1	1
High ACM	1	78	1	9	0	6	0	4	1	0
Middle ACST	3	0	62	0	29	0	0	3	1	2
Middle ACM	0	0	1	81	1	10	0	6	1	0
Low ACST	0	0	8	0	78	0	0	6	0	8
Low ACM	0	0	0	0	5	86	0	9	0	0
ACSM	1	1	2	3	4	3	84	0	1	1

decreased by 28.5%, which caused many outflow lakes to become inland lakes. At the same time, the area of the rivers reduced evidently, and the extent decreased by 9.03%, which caused numerous riverbeds to dry up and the runoff at the representative hydrologic stations steadily reduced on-the- spot survey in the source region of the Yellow River (Liu & Zhang 2002).

Spatial changes of unavailable land types: In 2000-2015, the area changes of unavailable land ecotypes were expanding to different degrees in the source region of the Yellow River (Table 2). The development of land salinization was the most intensive among them. Its extent increased by 106.63 % (annual mean increase was 7.11%). The development speed of land desertification was very quick. Its extent increased by 25.65% (annual mean increase was 1.83%). The distribution area of BR&L and bottomland whose vegetative cover was less than 5% was increased by 3.95%. The results show that the development of the land desertification was very intensive in the source region of the Yellow River in 2000-2015. The expansion extents of the land salinization, desertification and the bared land were all more than 3%. The land salinization and desertification were the most intensive among them.

Dynamic transfers of the grassland: From Table 3, we can see that 15% high cover degree and 29% middle vegetative cover ACST changed separately into low vegetative cover ACST in the source region of the Yellow River in 2000-2015, and the rest of 8% high vegetative cover ACST changed into middle vegetative cover ACST. The decline in the vegetative cover was the main transfer direction of the ACST in the source region of the Yellow River. 1% high vegetative cover ACST and 2% middle vegetative cover ACST were desertification. 22% of the low vegetative cover ACST transferred, of which 6% changed into BR&L, 8% changed into sandy land, and the rest of 8% changed into middle vegetative cover ACST. The vegetative cover of 15% high vegetative cover and 10% middle vegetative cover ACM declined. Moreover, 4% and 6% of them

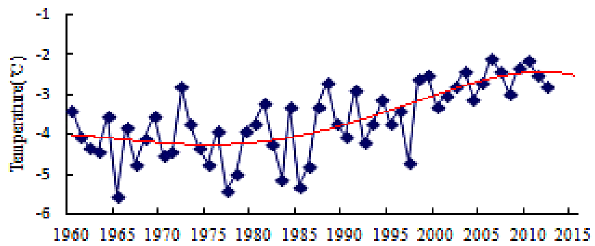

Fig. 3: The changes of annual temperature from 1960 to 2015.

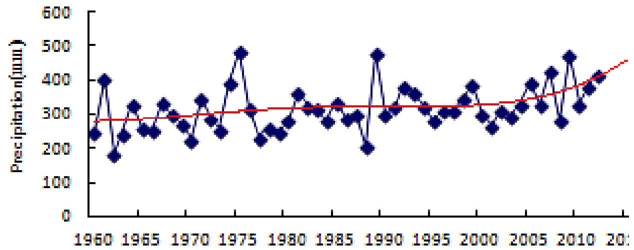

Fig. 4: The changes of annual precipitation from 1960 to 2015.

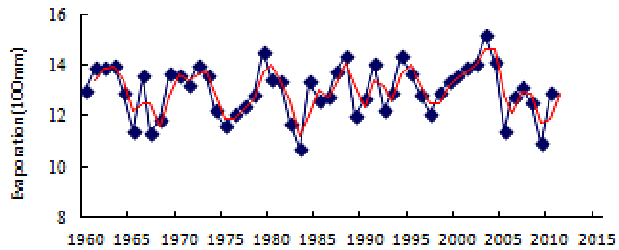

Fig. 5: The changes of annual evaporation in from 1960 to 2015.

changed respectively into BR&L, and each 2% of them changed into ACST. 14% low vegetative cover ACM changed, of which 9% changed into BR&L. The rest of 5% changed into ACST. Because of the swamp drying up, 7% ACSM changed into ACM. Another 7% changed into ACST, and still another 1% was desertification.

Dynamic transfers of other land ecotypes: As given in Table 4, the direction and extent of other land ecotypes' transfers in the source region of the Yellow River in 2000-2015, 18% river area and 15% lake area had landscape pattern changes. They changed primarily into sandy land, bare rock and bare land, of which 54.63 km^2 changed into sandy land and 86.82 km^2 changed into bare rock and bare land. 12% sandy land area had landscape pattern changes, of which 10% changed into the half fixed and fixed sand dune (the area was 149.03 km^2), with the emergence of low cover degree ACST. Another 34.1 km^2 sandy lands changed into bare rock and bare land. At the same period, 682.26 km^2 other land types changed into sandy land, which was 4 times the area that sandy land changed into grassland. The area of salt lick was small in the source region of the Yellow River, but 5.42 km^2 other land types changed into salt lick in the past 15 years. For example, the water area of lakes had to dry up and the land cover had desertification. The area of salinization was a time of original salt lick. The area of glaciers was small in the source region of the Yellow River, but the variety of glaciers was very remarkable. About 17.2% glaciers changed into bare rock because of glaciers shrinking in 2000-2015.

DRIVING FORCES

Climate changes: Climate changes and its impact on the environmental condition have attracted a great deal of interest (Berger et al. 1987, Karl et al. 1995). Climate change is a major factor, and had two main aspects: temperature and precipitation. In the past 50 years, the annual temperature of the source region shows a tendency to become warm as a whole (Fig. 3). The temperature was warm in 1950s, reduced in 1960s, fluctuated and went up in 1970s, was a high period in 1990s, which continued in 2000s. From the late 1970s, a significant increase in air temperature, by about 0.05°C per year in the study area was observed. In the past 50 years, the annual precipitation in the source region of the Yellow River has increased as a whole (Figs. 4 and 5), but the increase of the distribution was mainly in winter and spring. The precipitation in summer playing an important role in the vegetation growing shows a tendency to reduce obviously.

Such climate changes have seriously affected the vegetation of ACST and ACSM. During the vigorous growth period, i.e. at the peak period for water requirement, the region's climate became more arid and hence, the growth and reproduction of the vegetation were seriously affected (Cheng & Liang 1998). The area of high-middle cover degree ACST and high cover degree ACM degraded notably because of drought. The tendency of warming will accelerate glaciers and snow to melt in a large amount, and make the glaciers bottom and permanent snow appear shrinking. With the large area reduction of the snow and the rapid reduction of the water resource, the eco-environment of the study area has become worse, which makes the land desertification and soil erosion even more rapid.

Rodent damages: According to the investigations of Cheng & Wang (1998), rodent and insect damages are serious on the vast tracts of the grassland in the source region of the Yellow River. We found that the mice are indulging in willful persecution in the study area. For example, the *Ochotona curzoniae*, the *Myospalas baileyi*, and the *Microtus oeconomus* have increased sharply, of which the

Table 4: Transition matrices for other land types from 2000 to 2015 in the source region (unit: km^2).

2000	2015						
	River	Lake	Glacier	Sandy land	Salt lick	BR&L	Low ACST
River	1,796.2	0	0	24.65	0.08	69.08	0
Lake	1.6	1,493.6	0	29.98	4.01	17.74	0
Glacier	0	0	103.28	0	0	21.59	0
Sandy land	9.57	1.42	0	1,370.1	1.33	34.1	149.03
Salt lick	0	0	0	0	6.45	0	0.02
BR&L	46.28	3.85	0	30.23	0	12,422.6	0

Ochotona curzoniae is the most dangerous and the *Myospalas baileyi* take the second place (Xu et al. 2004). Rodent damages are a natural enemy for the grassland. It impacts on the grassland vegetation in many aspects. They gnaw the stem leaves of plants, reducing natural grass resources directly. For example, the *Ochotona curzoniae* and the *Microtus oeconomus* regard the stems, leaves, flowers and fruits of various good grass as their main food. They excavate the cave, and destroy the grassland. The *Myospalas baileyi* lives underground, has very strong ability to excavate and gnaw the plant rhizome, cuts off the plant root system, puts a large number of heart soil out of the ground to form many mounds and these mounds press and bury the vegetation.

Rodent damages have caused the decline of the grassland cover, the good grass reduction, the poisonous grass increase, and the grassland productivity drop. Some lush grassland has turned to "back-soil flats" and bare land. The statistics show that 50% "back-soil" grassland resulted from the reason of rodent damages in the source region of the Yellow River. Up to now, about over 1/3 of the natural grasslands are in the state of degradation in various degree. Nearly 1×10^4 hm^2 natural grasslands have been in degradation and desertification. Rodent damages not only destroyed the grassland resource, but also reduced the ability of the self-restraint humidity in the grassland, which is unfavourable for the productivity of grassland ecosystem to be improved and kept up in this area.

Human activities: In the source region, farmland accounted for less than 1% of the total area, and livestock grazing on natural rangeland was the main economic activity (Song et al. 2009). According to Wang et al. (2001), the actual carrying capacity greatly exceeded the theoretical carrying capacity. In addition, grazing is unbalanced between the seasons. As a result of overgrazing, lack of scientific management and protective measures, much grassland was in degradation in different degrees. Since 1980s of the 20th century, only pursuing the amount of livestock in a lot of pastoral area, overgrazing, the livestock, such as cattle and sheep, etc., gnaw and trample on the grassland repeatedly without the chance of rehabilitation, which leads to the grassland and eco-environment degradation. Take Madoi County for an example, which is known as "the richest County in China" in the 1970s. It now becomes the poorest county in China because of the grassland degradation and reduction of livestock resulting from extreme acceleration of livestock amount (once the livestock amount per people exceeded 100), overgrazing and rodent damages.

Gold mining was another important reason of eco-environment destruction in this area. The source region of the Yellow River is rich in gold, and famous for its large area of alluvial gold and high quality. Since 1980s, a large number of gold-diggers have crowded into the source region of the Yellow River, and the local population expanded rapidly from more than 10,000 people to about 100,000. They dug and quarried the gold excessively without any control in some areas, which has not only destroyed the gold resources, but also led to more serious consequence that ruined the grassland resources, destroyed the beneficial cycle of the ecosystem, and caused the land desertification and soil erosion. The whole Madoi County had quarried the gold illegally from 1980 to 2015. A 2.8 t of alluvial gold has been lost. 21% of the vegetation (the grassland) has been destroyed. The wild animal quantity in an area of 21.33×10^4 hm^2 has decreased by 31%, and the process of land desertification and soil erosion has accelerated.

Additionally, excessively collecting Chinese herbal medical materials and cutting the firewood without control accelerated the grassland degradation. The source region of the Yellow River is abundant in medical plant resources, so a large number of peasants and herdsmen collect the crude medicinal materials from the grassland of this area (Wu 2000), such as *Glycyrrhiza uralensis*, *Cordyceps sinensis*, *Rheum palmatum*, *Saussurea medusa*, etc., which formed countless small mounds and pits spreading all over the place. The vegetation was destroyed seriously, leaving the hidden danger for the grassland ecosystem. Meanwhile, in order to solve the fuel shortages, the sparse bushes (such as the

Salixoritrepha bushes) on grassland were cut down as fuel wood without planning. Thus, the vegetation was destroyed and the land desertification was aggravated.

DISCUSSION AND CONCLUSION

The source region of the Yellow River is the typical environmentally fragile region. In the past 15 years, the primitive eco-environment in the source region of the Yellow River has suffered destruction of certain degrees. It was mainly the forest and grassland degradation, land desertification, soil erosion aggravation, water resources reduction, etc. The degradation of high and middle cover ACST and high cover ACM was remarkable. They decreased respectively by 23.65% and 6.85%. The distributed area of ACSM decreased by 13.4%. The development trend of grassland was from high covering ACST to low covering ACST, and desertification, naked soil and rock evolution at the same time. The land desertification was very significant. The expanding range of land salinization, land decertification and naked land were above 3%, among them the salinization and the desertification of land were most serious. The glaciers and permanent snows were shrinking backward, of which the shrinking range of the glaciers was larger, decreasing by 17.24%. The lake water area shrinked greatly, reducing by 5.28%, of which the area of outflow lakes was reducing as the main fact (71.5%). A large number of outflow lakes were becoming inland lakes. The area of river water was notably decreased by 9.03%, which causes numerous riverbeds to dry up in the source region of the Yellow River.

The main driving forces included climate changes, ferocious rodent damages and unreasonable human activities, which aggravated the process of eco-environmental degradation. These outstanding problems seriously restricted sustainable development of the source region of the Yellow River and even the whole river basin. It is important to take scientific measures to protect and improve the eco-environment so as to maintain the ecological balance and promote the sustainable development of economy in the source region of the Yellow River.

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