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Grassland degradation in the "Three-River Headwaters" region, Qinghai Province

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Abstract: Supported by MSS images in the mid and late 1970s, TM images in the early 1990s and TM/ETM images in 2004, grassland degradation in the "Three-River Headwaters" region (TRH region) was interpreted through analysis on RS images in two time series, then the spatial and temporal characteristics of grassland degradation in the TRH region were analyzed since the 1970s. The results showed that grassland degradation in the TRH region was a continuous change process which had large affected area and long time scale, and rapidly strengthen phenomenon did not exist in the 1990s as a whole. Grassland degradation pattern in the TRH region took shape initially in the mid and late 1970s. Since the 1970s, this degradation process has taken place continuously, obviously characterizing different rules in different regions. In humid and semi-humid meadow region, grassland firstly fragmentized, then vegetation coverage decreased continuously, and finally "black-soil-patch" degraded grassland was formed. But in semi-arid and arid steppe region, the vegetation coverage decreased continuously, and finally desertification was formed. Because grassland degradation had obviously regional differences in the TRH region, it could be regionalized into 7 zones, and each zone had different characteristics in type, grade, scale and time process of grassland degradation.

Keywords: "Three-River Headwaters" region; Qinghai; grassland degradation; remote sensing; spatial pattern; temporal process

1 Introduction

The "Three-River Headwaters" region (TRH region), as the headwaters of the Yellow River, the Yangtze River and the Lancang River, is located in southern Qinghai, hinterland of the Qinghai–Tibet Plateau. It is also known as China's "Water Tower". Recently, grassland ecosystem has continuously degraded in this region, due to global warming and disturbances of frequent human economic activities. Currently, the degradation of grassland ecosystem has attracted interest of scientists in the world.

Grassland degradation represents the decline of grassland quality, productivity, economic

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potential and service function, biological diversity or complexity, the deterioration of grassland environment, being weaken or lost of grassland recovery ability (Li, 1997). Researches showed that grassland degradation had become a comprehensive trend in the TRH region.

According to investigation analysis, moderate or serious degraded grassland area accounted to 0.12 hundred million hm^2, accounting for 58% of the available grassland area. Yield per unit area declined 30%–50%, high quality forage decreased 20%–30%, poisonous weeds increased 70%–80%, grassland vegetation coverage decreased 15%–25%, and grass height of forage decreased 30%–50%, compared with that in the 1950s. For example, the average rate of grassland degradation in the source region of the Yellow River increased more than one times in the 1980s–1990s (Zhao *et al*., 2005). Chen (2005) found that moderate grassland degraded area was 5.7×10^6 hm^2 in the TRH region, occupying 55.4% of the available grassland area. Serious degraded grassland was named "black-soil-patch", of which area accounted to 1.8×10^6 hm^2, or 32.1% of the total grassland degraded area (Chen, 2005). Wang *et al*. (2001a) considered that degraded grassland area accounted for 34.34% of the total grassland area in six counties, including Dari, Maduo, Maqin, Zhiduo, Qumalai and Zaduo. For example, serious degraded grassland area accounted for 26.79% of the total degraded grassland area, which was primarily distributed in Dari, Maduo and Qumalai. The results indicated that grassland degradation was very serious in the source region of the Yellow River (Wang *et al*., 2001a). Coverage decrease, sandification and salification were the typical characteristics of grassland degradation (Liu, 2006; Zhang *et al*., 2006). Dari was the most serious degraded county in the TRH region. From the mid-1970s to 2000, the quality of alpine meadow declined continuously in Dari. Degraded grassland area was 4.29×10^5 hm^2, accounting for 29.39% of the total land area of Dari (Liu *et al*., 2006).

Grassland ecosystem is the main ecosystem in the TRH region. In recent years, some scholars have studied grassland degradation in the TRH region using RS technology (Chen, 1998a; 1998b; Tu *et al*., 1999; Wang *et al*., 2001b; Yang *et al*., 2006; Feng *et al*., 2005).

In order to acquire objectively spatial-temporal processes of grassland degradation, MSS images in the mid and late 1970s, TM images in the early 1990s and TM/ETM images in 2004 were used. Grassland degradation in the TRH region was interpreted through analysis on RS images in two time series, then the spatial and temporal characteristics of grassland degradation in the TRH region were analyzed since the 1970s.

2 Materials and methods

There are two kinds of methods to extract grassland degradation information from RS data: (i) indirect extraction based on the relationship between grassland degradation indicators and retrieval of vegetation parameter from RS data; and (ii) information extraction directly by interpretation based on RS images. The former is widely applied in analyzing grassland degradation based on the relationship between vegetation index, for example, NDVI, and grassland degradation indicators, such as vegetation coverage and biomass (Zhong *et al*., 2003; Li *et al*., 2003; Dai *et al*., 2006). But there are still great differences between grassland degradation classification information and demand of grassland studies, and the extraction precision is also very low, because of restriction of RS retrieval of vegetation parameter not directly corresponding to grassland degradation indicators and the influence of some uncer-

tain factors. The latter not only has the rigorous requirement for the selections of RS data sources and accurate data handling, but also needs interpreters having overall comprehension of grassland degradation status in the study region, but the precision and efficiency of extracting degradation information is relatively high (Chen *et al*., 1998a; 1998b; Tu *et al*., 1999; Shi *et al*., 1999; Liu, 2007). This method is used in the grassland degradation study in the "Three- River Headwaters" region in Qinghai Province.

In the process of building grassland degradation data set of the TRH region, a RS classification system was drafted. According to national standard of "parameters fo degradation, sandification and salification of rangelands" (GB19377-2003) (GAQSIQ-PRC, 2004), grassland degradation in the TRH region can be classified into 7 first categories, which includes fragmentation, coverage decrease, fragmentation and coverage decrease compound, swamp meadow drying, sandification and salification, grassland improving and bettering, and no degradation, then they can be further classified into 21 subcategories based on grassland degradation degree. On the other hand, an effective research team was organized to work on remotely sensed data through human-machine interactive interpretation for guaranteeing classification consistency and accuracy. The workflow of this integration is displayed in Figure 1.

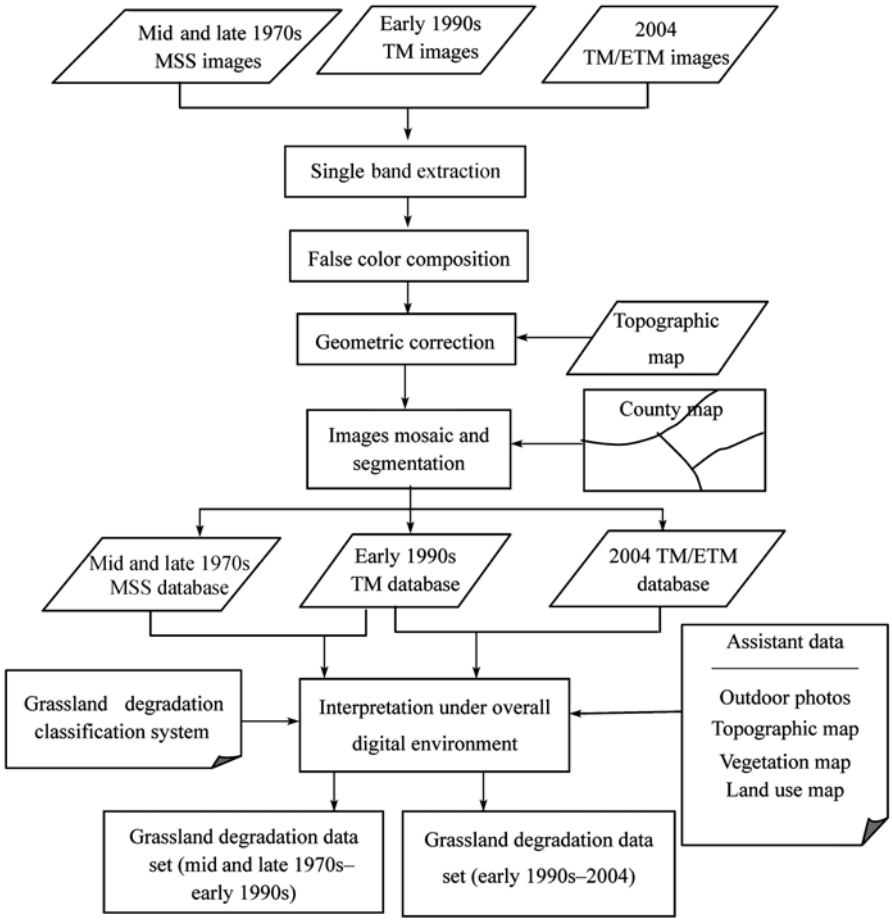

Figure 1 The technical process of interpreting grassland degradation by RS in the TRH region

The main data sources were MSS digital images in the mid and late 1970s, TM digital images in the early 1990s and TM/ETM digital images in 2004 (28 scenes covering the whole TRH region in each time periods respectively). In order to reflect grassland growth, RS images which acquired time concentrating on July and August were used. The spatial resolution of MSS digital images is 80 meters, but it can provide grassland information in the mid and late 1970s. And the precision of interpretation was ensured through analysis and comparison of MSS and TM/ETM images. A series of image processing was done for MSS and TM/ETM images in three time periods, such as single band extraction, false color composition, geometric correction, images mosaic and segmentation, standard false color image data set was built based on county-level administrative unit. The outline of grassland degradation type was delimited by comparison of RS images in different time periods, with the references from the former. Finally, grassland degradation thematic maps were completed in two time periods, from the mid and late 1970s to the early 1990s (former period) and from the early 1990s to 2004 (latter period).

3 Spatial pattern of grassland ecosystem in the TRH region

The grassland ecosystem is primary in the TRH region. Grassland area accounts for 65.37% of the total land area. Figure 2 shows the locations and distributions of grassland type in the TRH region, the main grassland type is alpine meadow and alpine steppe, which accounts for 76.18% and 23.36% of the total grassland area respectively. Alpine meadow is absolutely dominant in the TRH region, which can be classified into alpine steppe meadow, typical alpine meadow and alpine swamp meadow. Alpine steppe meadow is an intermediate type between alpine meadow and alpine steppe, mostly located on below parts of mountain sunny slope, broad valley, valley terrace and low hilly with an altitude of about 3200–4700 m. The vegetation coverage of alpine steppe is about 70%–90%. Because of enough high quality forage, it is valuable pasturage in the TRH region. Typical alpine meadow is a common alpine meadow type in the TRH region, located on parts of beach land, broad valley, level

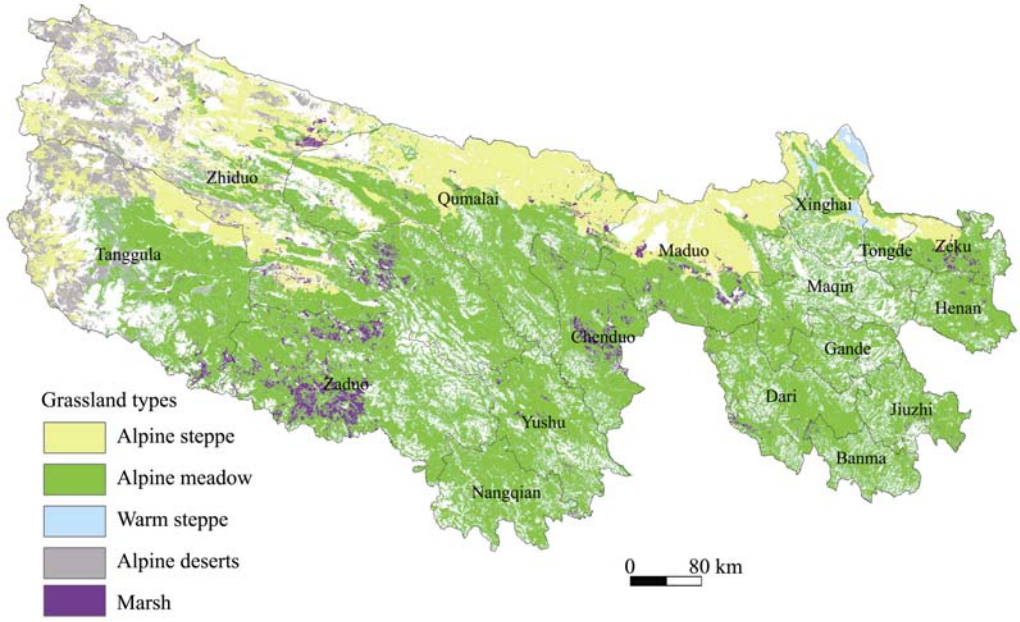

Figure 2 Spatial pattern of grassland types in the TRH region

ground with an altitude of about 3200–4700 m, with good drainage and moderate humidity conditions. The coverage of typical alpine meadow is about 70%–90%, and community structure is simple without clear differentiation. Alpine swamp meadow is an intermediate type between meadow and swamp, located on parts of lake side, intermontane basin, lower terraces beside rivers, saddle of watershed in mountain, bottom of snow belt in mountain, with relatively lower altitude, impeded drainage, moisture soil, no good aeration conditions. The coverage of alpine swamp meadow is about 80%–90%. It can provide much fodder and be suitable for grazing with rich species composition and high forage yield.

The percentage of high, medium and low coverage grassland area to total grassland area is 38.02%, 21.39% and 40.60% respectively. Figure 3 shows the high, medium and low coverage grassland distribution pattern. High coverage grassland is mainly distributed in the eastern, central and southern parts of the TRH region, where hydrothermal conditions are good, and vegetation coverage is more than 50%. Medium coverage grassland is mainly distributed in the north of Dari and Maduo counties, and some parts of Zaduo County, where the hydrothermal conditions are poor, the influence of human activities is intense, and vegetation coverage is about 20%–50%. Low coverage grassland is mainly distributed in the west and north of the study area, such as Tanggula County, west of Zhiduo County, north of Qumalai County, where the hydrothermal conditions are poor and the vegetation coverage is about 5%–20%.

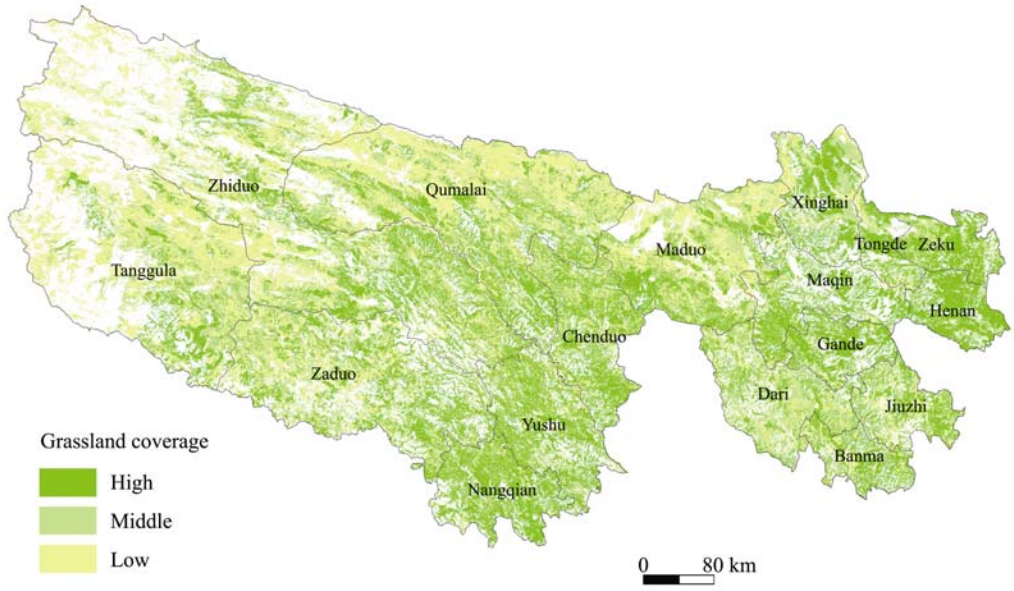

Figure 3 Spatial pattern of grassland coverage in the TRH region

4 Spatial and temporal characteristics of grassland degradation in the TRH region

4.1 Characteristics of grassland degradation in the TRH region

According to analysis on MSS images in the mid and late 1970s, TM images in the early 1990s and TM/ETM images in 2004, the spatial variability of type and degree of grassland degradation was distinct. It was particularly important that the locations of grassland degra-

dation identified on TM/ETM images from the early 1990s to 2004 could be found on MSS images in the mid and late 1970s, and they had the same texture property (Figures 4 and 5). Researches had shown that the grassland degradation pattern in the TRH region formed basically in the mid and late 1970s (Figures 6 and 7). The current situation of grassland degra-

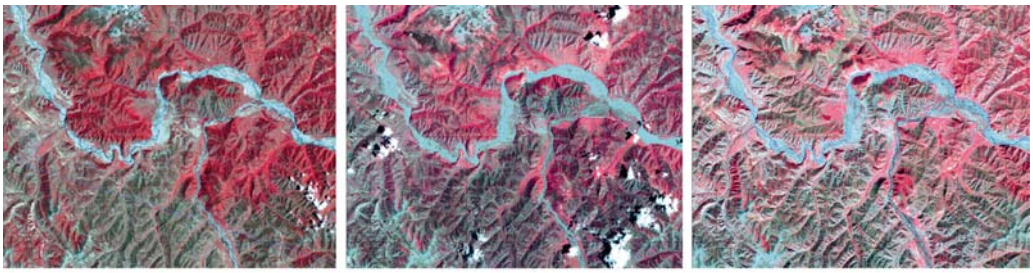

Figure 4 Remote sensing image characteristics of grassland degradation in Jianshe of north Dari

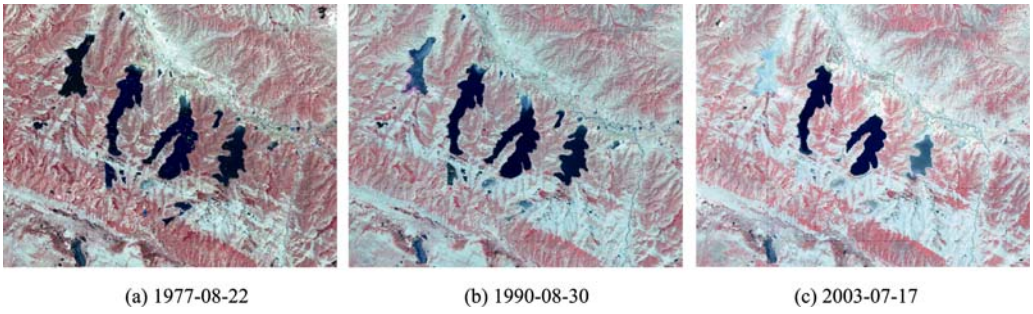

Figure 5 Remote sensing image characteristics of grassland degradation in Xingxinghai of middle Maduo

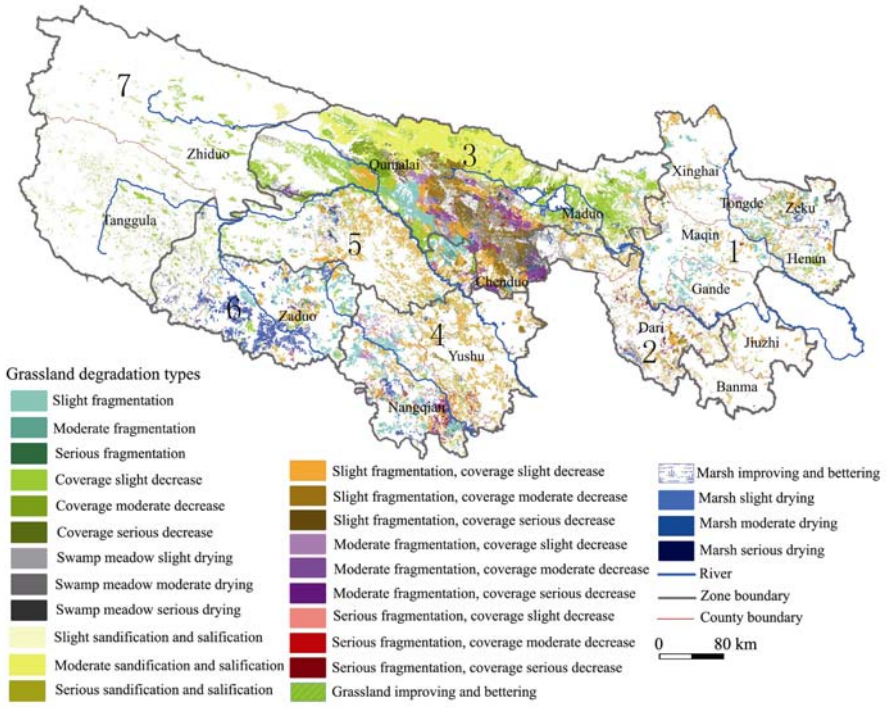

Figure 6 Grassland degradation from the mid and late 1970s to the early 1990s in the TRH region

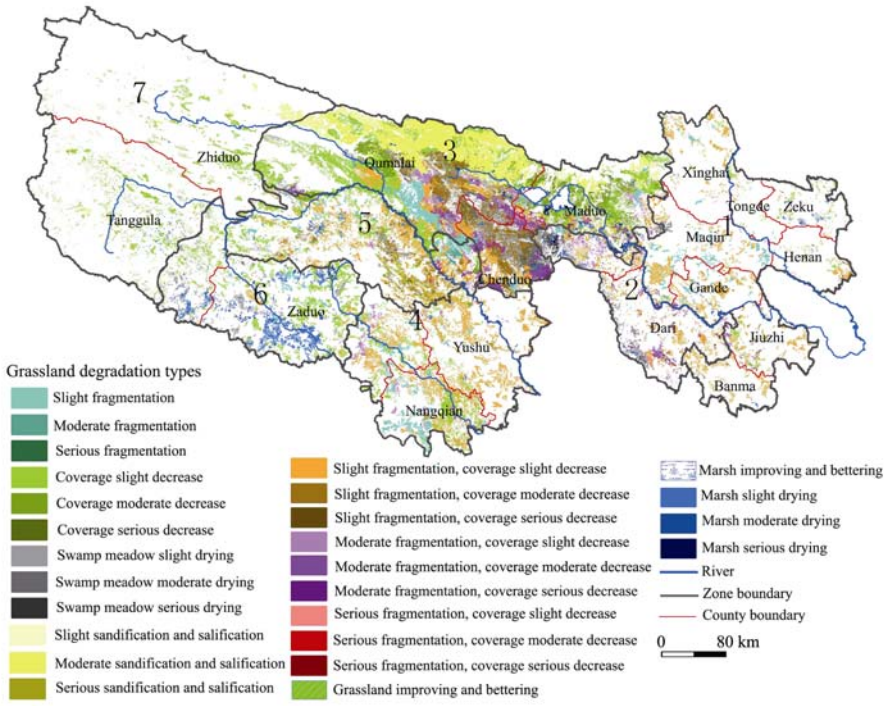

Figure 7 Grassland degradation from the early 1990s to 2004 in the TRH region

dation was the result of the synthesizing process of grassland degradation in the period before the mid and late 1970s and during recent 30 years.

Statistical results of spatial data sets of grassland degradation showed that grassland degraded area was 7.64×10^6 hm^2 in the former period, accounted for 32.83% of the total land area. In the latter period grassland degraded area was 8.41×10^6 hm^2 (36.12%), an increase of 3.87% (Table 1).

Statistical results of grassland degradation degree (Table 2) showed that slight and moderate degradation were the main types and serious degradation only occurred in some parts of the TRH region (Figures 6 and 7). And the area of slight degradation occupied 22.88% of the total grassland area in the former period, and increased to 23.93% in the latter period, An increase of 1.05%. On the other hand, the area of moderate degradation occupied 9.5% of the total grassland area in the former period, and increased to 11.74% in the latter period, an increase of 2.24%.

Compared with grassland degraded area in each county, grassland degradation mainly occurred in Qumalai, Chengduo and Maduo counties, and grassland degraded area accounted for over 40% of the total land area each. For example, grassland degraded area of Qumalai and Chengduo counties was large, occupying more than 60% of the total land area, but grassland degradation extent in Xinghai, Banma, Jiuzhi and Tanggula was relatively small, accounting for 10% of the total land area since the 1970s (Table 3).

Table 1 Grassland degraded area in the TRH region

Grassland degradation type	Mid and late 1970s–early 1990s (former period)		Early 1990s–2004 (latter period)	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Slight fragmentation	689432	2.96	473532	2.03
Moderate fragmentation	36040	0.15	36008	0.15
Serious fragmentation	247	0.00	1257	0.01
Coverage slight decrease	1652559	7.10	2092898	8.99
Coverage moderate decrease	152600	0.66	457746	1.97
Coverage serious decrease	48002	0.21	26324	0.11
Swamp meadow slight drying	594230	2.55	688219	2.96
Swamp meadow moderate drying	138384	0.59	183209	0.79
Swamp meadow serious drying	0	0.00	18383	0.08
Slight sandification and salification	280167	1.20	342064	1.47
Moderate sandification and salification	831431	3.57	915731	3.93
Serious sandification and salification	0	0.00	3303	0.01
Slight fragmentation, coverage slight decrease	2111929	9.07	1975692	8.48
Slight fragmentation, coverage moderate decrease	577295	2.48	608128	2.61
Slight fragmentation, coverage serious decrease	6452	0.03	2954	0.01
Moderate fragmentation, coverage slight decrease	205266	0.88	265766	1.14
Moderate fragmentation, coverage moderate decrease	271200	1.16	268191	1.15
Moderate fragmentation, coverage serious decrease	29496	0.13	30752	0.13
Serious fragmentation, coverage slight decrease	1134	0.00	5858	0.03
Serious fragmentation, coverage moderate decrease	5202	0.02	3910	0.02
Serious fragmentation, coverage serious decrease	13424	0.06	10341	0.04
Grassland improving and bettering	67465	0.29	6159	0.03
Marsh slight drying	185576	5.72	308155	11.74
Marsh moderate drying	25117	1.02	68468	2.20
Marsh serious drying	853	0.05	16729	0.40
Marsh improving and bettering	98212	0.43	0	0.00
Total marsh degradation	211546	6.79	393352	14.34
Total grassland degradation	7644490	32.83	8410266	36.12

Table 2 Grassland degradation degree in the TRH region

Degradation degree	Mid and late1970s–early 1990s			Early 1990s–2004		
	Area (hm^2)	Percentage (%)	Rate (hm^2/a)	Area (hm^2)	Percentage (%)	Rate (hm^2/a)
Slight degradation	5328317	22.88	380594	5572405	23.93	428647
Moderate degradation	2212216	9.50	158015	2734779	11.74	210368
Serious degradation	103957	0.45	7426	103082	0.44	7929
Improving and bettering	67465	0.29	4819	6159	0.03	474

Table 3 Grassland degraded area in different counties in the TRH region

County	Mid and late1970s–early 1990s		Early 1990s–2004	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
Banma	25371	5.74	65537	14.85
Chengduo	747397	63.33	750358	63.58
Dari	260586	24.21	220124	20.45
Gande	79020	15.76	100207	19.97
Henan	90617	17.22	35989	6.85
Jiuzhi	49508	8.2	93828	15.52
Maduo	890278	46.69	1056578	55.42
Maqin	155738	19.97	184835	23.70
Nangqian	329156	36.42	402500	44.58
Qumalai	2864930	79.54	2932230	81.41
Tanggula	279657	10.94	354684	13.88
Tongde	76360	24.35	19106	6.1
Xinghai	101524	12.07	89089	10.6
Yushu	308819	27.61	304566	27.22
Zaduo	550366	23.02	648990	27.14
Zeku	118740	21.78	38269	7.02
Zhiduo	716423	17.8	1113376	27.66

4.2 Spatial pattern of grassland degradation in the TRH region

Because of regional differentiation in climate, hydrothermal conditions, topography and geomorphology and human activities, spatial heterogeneity in the type and degree of grassland degradation was obvious in the TRH region (Figures 6 and 7). According to the spatial pattern of grassland degradation, a regionalization of grassland degradation was designed. The main principle and the basis of the characteristic for regionalization had been established according to the spatial distribution, extent, degree and temporal process of grassland degradation through qualitative and quantitative analysis (Table 4). Then the regionalization of grassland degradation was completed, including 7 zones: (1) small range, slight degree and continuous degradation in eastern 8 counties; (2) medium range, slight-moderate degree and continuance degradation in Dari and southern Maduo; (3) large range, moderate degree and continuance degradation and desertification in northern Maduo, Chengduo and majority of Qumalai; (4) medium range, slight-moderate degree and continuous degradation in Yushu, Nangqian, southern Chengduo and eastern Zaduo; (5) larger range, slight-moderate degree and continuance degradation in central-eastern Zhiduo and southern Qumalai; (6) small-medium range, slight degree degradation and partial improvement in central-western Zaduo and eastern Tanggula; and (7) small range, slight degree and continuous desertification in western Zhiduo and central-western Tanggula.

The spatial pattern characteristics of grassland degradation for each zone are as follows:

(1) Small range, slight degree and continuous degradation in eastern 8 counties In this zone, grassland degraded area was small, and degradation degree was stronger in the north and east than that in the south and west. Grassland degradation mainly occurred at relatively high altitude in ring-type distribution, of which the core was Nianbaoyuze in the Animaqing Mountains. In addition, slight drying and salification degradation mainly occurred in the swamp meadow which located on level valley terrace and low beach land in eastern Zeku and some parts of Henan.

Table 4 The nominating principles of regionalization of grassland degradation in the TRH region

Range	Name	Small range, small-medium range	Medium range	Larger range, large range
	Principles	P is lower than 20%, and if p is more than 20%, named as small-medium range	P is more than 20% and lower than 35%	P is more than 35%, and if p is more than 50%, named as large range
Degree	Name	Slight	Moderate-slight	Slight-moderate, moderate
	Principles	SP is lower than 15%, or MP is lower than 5%	SP is more than 10% and lower than 30%, and MP is more than 5% and lower than 10%	SP is more than 30%, if MP is more than 10% and lower than 30%, named as slight-moderate, and if MP is more than 30%, named as moderate
Process	Name	Continuous	Continuance	
	Principles	The degraded area has no great changes in two periods, and moderate degradation does not obviously increase in the latter period	The degraded area has no great changes in two periods, and moderate degradation obviously increases in the latter period	

P–percentage of grassland degraded area to total grassland area; SP–percentage of slight degraded area to total grassland area; MP–percentage of moderate degraded area to total grassland area

(2) Medium range, slight-moderate degree and continuance degradation in Dari and southern Maduo In this zone, grassland degraded area occupied about 30% of the total land area, and grassland degradation mainly occurred on sunny or gentle slopes at low altitude. Since the mid and late 1970s, the area of alpine shrub, swamp meadow and alpine sparse vegetations continuously decreased, and the area of barren land increased constantly. The serious degradation occurred in the alpine meadow and grassland near the settlements or in valley which had more intense grazing activities.

(3) Large range, moderate degree and continuance degradation and desertification in northern Maduo, Chengduo and majority of Qumalai Grassland degradation in this zone was most serious in the TRH region since the mid and late 1970s, and the grassland degraded area occupied more than 70% of the total land area. It showed that obvious sandification and salification occurred in the north and coverage decrease occurred in lower margin of bare rock and gravel land in the south. On the other hand, the compound degradation of fragmentation and coverage decrease mainly occurred on sunny and gentle slopes, valley terrace and beach land.

(4) Medium range, slight-moderate degree and continuous degradation in Yushu, Nangqian, southern Chengduo and eastern Zaduo The grassland degraded area occupied more than 30% of the total land area. Degradation mainly occurred from mountain top to piedmont. The type of degradation transformed from the coverage decrease of sparse vegetation and cushion vegetation around flow stone hillside of high mountains to fragmentation and coverage decrease compound degradation of alpine meadow and slight drying of swamp meadow. From south to north, the type of grassland degradation transformed from slight fragmentation to compound degradation. In addition, the phenomenon of coverage decrease occurred in some parts of the river basin, lee and sunny slopes.

(5) Larger range, slight-moderate degree and continuance degradation in central-eastern Zhiduo and southern Qumalai Grassland degradation in this zone decreased from east to west and from north to south. Grassland degradation is most serious in Qumalai county to the south of Tongtian River in the east. Swamp meadow drying mainly occurred in some

parts of Yaqu Basin, near the rivers to the east of Kouqianqu, alpine meadow and gorge region.

(6) Small-medium range, slight degree degradation and partial improvement in central-western Zaduo and eastern Tanggula Grassland degradation decreased from east to west. The compound degradation of fragmentation and coverage decrease mainly occurred in the east and was sparsely distributed in the west. On the other hand, around the glacier margin of Tangula Mountain, grassland became better locally due to climate warming which increased melting water.

(7) Small range, slight degree and continuous desertification in western Zhiduo and central-western Tanggula The grassland degraded area occupied about 10% of the total land area without obvious trend of enhanced degradation. Due to zonal natural conditions and relatively few human activities, grassland desertification is dominant and the new grassland degradation is insignificant.

4.3 Temporal process of grassland degradation in the TRH region

With the support of MSS images in the mid and late 1970s, TM images in the early 1990s and TM/ETM images in 2004, the statistical results of grassland degradation showed that the degradation process was taking place continuously and obviously characterized different rules in different regions since the mid and late 1970s. On horizontal regional differentiation from southeast to northwest, there were different degradation processes and rules for meadow and steppe ecosystem. For example, in humid and semi-humid meadow regions, grassland firstly fragmentized, then vegetation coverage decreased continuously, and finally "black-soil-patch" degraded grassland was formed. But in semi-arid and arid steppe region, the vegetation coverage decreased continuously, and finally desertification was formed.

The temporal process of grassland degradation in different counties (Table 3) showed that grassland degradation occurred in the former period and then worsened in Banma, Zhiduo, Nangqian, Qumalai and Maduo counties, and grassland degradation had same trend in Chengduo, Yushu and Xinghai counties, and grassland degradation degree decreased in Tongde, Zeku and Dari counties. For example, in Maduo County, the grassland degraded area was 46.69% in the former period, and increased to 55.42% in the latter period, up 8.73%. And in Yushu County, the grassland degraded area maintained an account of 27% in the two periods, and the change was very little. While in Tongde County, the grassland degraded area in the former period was 24.35%, and decreased to 6.1% in the latter period, decreased by 18.25%, and the rate of grassland degradation was slow.

The statistical results (Table 5) showed that in the third zone, named large range, moderate degree and continuance degradation and desertification in northern Maduo and Chengduo and majority of Qumalai, grassland degradation was the most serious. In the former period, grassland degraded area was 4,096,271 hm^2 (73.91%). In the latter period, grassland degraded area increased to 4,256,363 hm^2 (76.79%), an increase of 2.88%. In the fifth zone, named larger range, slight-moderate degree and continuance degradation in central-eastern Zhiduo and southern Qumalai, grassland degradation was only inferior to that of the third zone. In the former period, the grassland degraded area was 761,240 hm^2 (33.13%). In the latter period, the grassland degraded area increased to 1,097,348 hm^2 (47.75%), an increase of 14.62%.

Table 5 Grassland degraded area in different zones in the TRH region

Degradation zone	Mid and late1970s–early 1990s		Early 1990s–2004	
	Area (hm^2)	Percentage (%)	Area (hm^2)	Percentage (%)
1	696778	15.35	626838	13.78
2	418906	26.39	442177	27.86
3	4096271	73.91	4256363	76.79
4	915657	29.84	1009415	32.88
5	761240	33.13	1097348	47.75
6	421575	17.31	524510	21.56
7	334063	8.74	453615	11.86
Total	7644490	32.83	8410266	36.12

From the mid and late 1970s to 2004, the spatial differentiation of grassland degradation was obvious in the TRH region. The 7 zones have different characteristics in temporal process of grassland degradation (Figures 8 and 9). The dynamic characteristics of the grassland degradation in each zone are as follows:

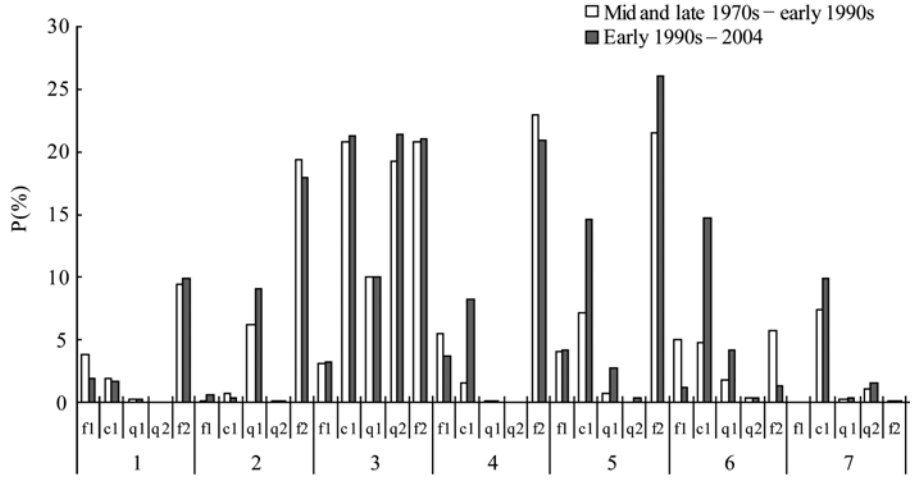

Figure 8 Grassland degradation type in different zones in the TRH region (P–percentage of grassland degraded area to total grassland area; f1–fragmentation; c1–coverage decrease; q1–swamp meadow drying; q2–sandification and salification; f2–is fragmentation and coverage decrease compound)

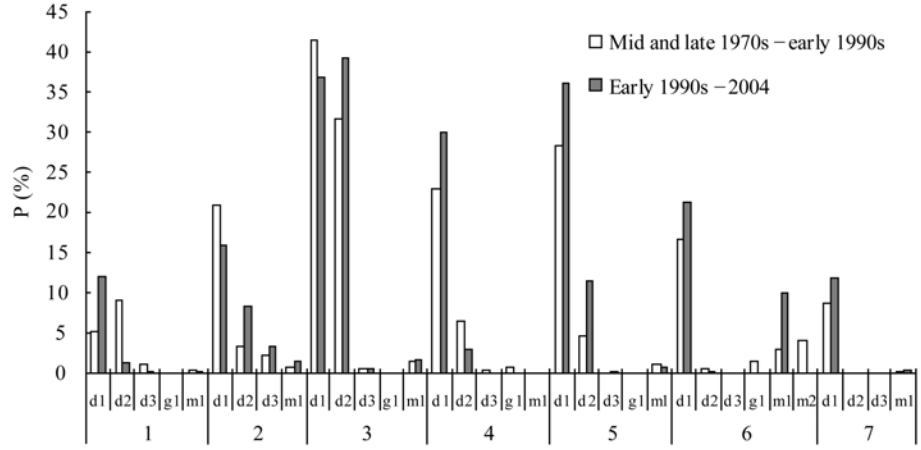

Figure 9 Grassland degradation degree in different zones in the TRH region (P–percentage of grassland degraded area to total grassland area; d1–slight degradation; d2–moderate degradation; d3 is serious degradation; g1–grassland improving and bettering; m1 is marsh degradation; m2–marsh improving and bettering)

(1) Small range, slight degree and continuous degradation in eastern 8 counties In this zone, grassland degradation type was mainly slight fragmentation and coverage decrease. During recent 20 years, grassland degradation still continuously took place, and the change of the total grassland degraded area presented a slightly decreasing trend. For example, in the former period, grassland degraded area was 696,778 hm^2 (15.35%). In the latter period, grassland degraded area decreased to 626,838 hm^2 (13.78%), a decrease of 1.57%.

(2) Medium range, slight-moderate degree and continuance degradation in Dari and southern Maduo Grassland degradation type was mainly slight fragmentation and coverage decrease, which primarily occurred in the former period, and the swamp meadow and marsh drying increased sharply in the latter period. For example, in the former period, grassland degraded area was 418,906 hm^2 (26.39%). In the latter period, grassland degraded area increased to 442,177 hm^2 (27.86%), an increase of 1.47%.

(3) Large range, moderate degree and continuance degradation and desertification in northern Maduo, Chengduo and majority of Qumalai Some grassland degradation types occurred in this zone, such as fragmentation, coverage decrease, compound degradation of fragmentation and coverage decrease, swamp meadow drying, sandification and salification, which were mostly slight and moderate. Since the 1990s, an increasing trend of grassland degradation has emerged. For example, in the former period, grassland degraded area was 4,096,271 hm^2 (73.91%). In the latter period, grassland degraded area increased to 4,256,363 hm^2 (76.79%), an increase of 2.88%.

(4) Medium range, slight-moderate degree and continuous degradation in Yushu, Nangqian, southern Chengduo and eastern Zaduo Grassland degradation type was mainly compound degradation of fragmentation and coverage decrease which was primarily caused by slight fragmentation. Since the 1990s, an increasing trend of grassland degradation has emerged. For example, in the former period, grassland degraded area was 915,657 hm^2 (29.84%). In the latter period, grassland degraded area increased to 1,009,415 hm^2 (32.88%), an increase of 3.04%.

(5) Larger range, slight-moderate degree and continuance degradation in central-eastern Zhiduo and southern Qumalai Grassland degradation type was mainly fragmentation and coverage decrease, mostly with swamp meadow drying phenomenon. And the general trend of grassland degradation was enhanced, especially in the latter period. For example, in the former period, grassland degraded area was 761,240 hm^2 (33.13%). In the latter period, grassland degraded area increased to 1,097,348 hm^2 (47.75%), an increase of 14.62%.

(6) Small-medium range, slight degree degradation and partial improvement in central-western Zaduo and eastern Tanggula Grassland degradation type was mainly coverage slight decrease, and there was a significant difference in different periods. For example, in the former period, grassland degraded area was 421,575 hm^2 (17.31%). In the latter period, grassland degraded area increased to 524,510 hm^2 (21.55%), an increase of 4.24%.

(7) Small range, slight degree and continuous desertification in western Zhiduo and central-western Tanggula Grassland degradation type was mainly coverage slight decrease, slight sandification and salification. Desertification degree became more serious in the latter period compared with that of the former period. For example, in the former period, grassland degraded area was 334,063 hm^2 (8.74%). In the latter period, grassland degraded area increased to 453,615 hm^2 (11.86%), an increase of 3.12%.

5 Conclusions and discussion

The obvious characteristics of grassland degradation in the TRH region in recent 30 years are as follows.

(1) The grassland degradation pattern in the TRH region had been formed basically in the mid and late 1970s. The locations of grassland degradation identified on TM/ETM images in the period from the early 1990s and 2004 could be found on MSS images in the mid and late 1970s, and they had the same texture property.

(2) Since the mid and early 1970s, the grassland degradation process has taken place continuously, obviously characterizing different rules in different regions. On horizontal regional differentiation from southeast to northwest, there were different degradation processes and rules for meadow and steppe ecosystem. In humid and semi-humid meadow region, grassland firstly fragmentized, then vegetation coverage decreased continuously, and finally "black-soil-patch" degraded grassland was formed. But in semi-arid and arid steppe region, the vegetation coverage decreased continuously, and finally desertification was formed

(3) Grassland degradation in the TRH region was a continuous change process which has large affected area and long time scale, and no intensification phenomenon has existed since the 1990s as a whole.

(4) Grassland degradation in the TRH region had obvious regional differences, and 7 zones can be identified. (a) Small range, slight degree and continuous degradation in eastern 8 counties; (b) Medium range, slight-moderate degree and continuance degradation in Dari and southern Maduo; (c) Large range, moderate degree and continuance degradation and desertification in northern Maduo, Chengduo and majority of Qumalai; (d) Medium range, slight-moderate degree and continuous degradation in Yushu, Nangqian, southern Chengduo and eastern Zaduo; (e) Larger range, slight-moderate degree and continuance degradation in central-eastern Zhiduo and southern Qumalai; (f) Small-medium range, slight degree degradation and partial improvement in central-western Zaduo and eastern Tanggula, (g) Small range, slight degree and continuous desertification in western Zhiduo and central- western Tanggula.

Because of regional differentiation in geographical background, climate change, hydrothermal conditions and grass-livestock conflicts, the great differences existed in types, degree, scale, and temporal process of grassland degradation in the 7 zones. So pertinent planning ecosystem recovery project was very important in each zone according to their regional differences. On the other hand, it is worth noting that grassland degradation shows not only in the decrease of vegetation coverage, height, biomass, soil bareness and grass exfoliation, but also in the structure change of grassland plant community, such as the decline of proportion of good forage, the increase of proportion of weeds, poisonous and harmful grasses. In the future, further field investigations will be needed by combining them with RS analysis to improve the accuracy of grassland degradation analysis.

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