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ORIGINAL ARTICLE

A review of formation mechanism and restoration measures of "black-soil-type" degraded grassland in the Qinghai-Tibetan Plateau

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Abstract The aim of this paper was to review the formation mechanism and restorative measures of the black-soil-type degraded grassland ecosystem of the source area of Yangtze and Yellow Rivers, Qinghai-Tibetan Plateau. The relationship among plants, animals, soil, climate change, human activity and the black-soil-type degraded grassland was analyzed based on a review of literature and report of previous investigations conducted by the authors. Degradation of the black-soil-type grassland was caused by a set of complex factors such as altitude range, district characteristics and weather conditions, which existed for a long period of time. Livestock overgrazing and climate dryness were the dominant factors that caused the degradation of the grassland in question. In addition, damages done by rodents, especially pikas (*Ochotona curzoniae*), via burrowing through the turf and gnawing at herbs have sped up the formation process of the degradation of the black-soil-type grassland. Furthermore, with the inflation of the population in the last 20 years, the influence of human activity on grassland degradation cannot be neglected. Based on the different successive stages of degradation of the black-soil-type grassland ecosystem, different restorative measures were suggested. The lightly and moderately degraded grasslands should be kept away from disturbance, such as fencing closure, weeding, fertilizing, using rodenticide, decreasing stocking rate, optimizing population structure stocked and slaughter ages; whereas the artificial and semi-artificial grassland establishment required to restore ecosystems should be applied to heavily and extremely degraded grasslands.

Keywords Black-soil-type · Degraded alpine grassland · Formation · Restoration · Qinghai-Tibetan Plateau

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Introduction

The Qinghai-Tibetan Plateau, the highest and youngest plateau on earth, is one of the most important components of natural ecosystems and among the most threatened landscapes in the world. The alpine meadow, which accounts for 90 % of the grassland area around the region of the plateau, is primarily located in the headwater region of several large rivers, including the Yellow, Yangtze and Lancang/Mekong rivers and therefore plays an important role in water conservation and the productivity of local grazing grassland (Wang et al. 2007; Feng et al. 2010). However, due to the frigidity of the climate in this region, the growth period of plants is very short (90–120 days) and forage yield is also low, which has led to the imbalance of seasonal pasture (warm season and cold season pasture) and overgrazing caused by the increasing number of livestock in the alpine meadow ecosystem. The combination of unsystematic management of feed and a highly variable climate has contributed to extensive ecological problems throughout the Qinghai-Tibetan Plateau (Shang and Long 2007). Currently, it was reported that the area of alpine pasture meadow that is degraded has reached 4.67×10^6 hm^2, which accounts for 25 % of the total area of this region and comprises approximately half of the total alpine grassland. In particular, the black-soil-type degraded grassland, also named "black-soil land", "black beach", "black slop" or "black mountain" (Ma et al. 1999; Shang and Long 2007), results from the surface layer, which ranges from 10 to 15 cm in depth, being totally removed by intensive grazing and activities of rodents, leaving the subsoil uncovered. The area then becomes bare land without vegetation in the cold season, which is followed by the land being covered with poisonous and ruderal plants that are inedible by livestock in the warm season. The area of this black-soil-type pasture has reached 2.13×10^6 hm^2, which accounts for 62.6 % of the total area of degraded pasture in the Qinghai Province, which leads not only to ecological problems but also greatly reduces the productivity of those grasslands (Ma and Lang 1998; Ma and Li 1999; Ma et al. 2002).

Literature review

The formation of black-soil-type degraded grassland

The degradation of the alpine meadow ecosystem and the disturbance caused by human activity have gradually brought about the deterioration of this natural habitat of animals and plants, leading to severe endangerment of 15–20 % of the total species, and gradual impoverishment of biodiversity. Many scientists have paid close attention to studies on the black-soil-type degraded alpine pasture meadow around the source region of the Yangtze and Yellow Rivers lying in the hinterland of Qinghai-Tibetan Plateau. Liu et al. (1999) has ascertained that the long-term decline of productivity either by overgrazing or by species turnover was the main reason for the results in degradation of alpine grassland, with increasing sapping and gnawing by pikas speeding up this process. Liu's general findings were supported by lots of works (Shang 2001; Li et al. 2003; Wu et al. 2009, 2010, 2011) wherein they reported that improvement in grassland productive forces and/or reduction of damage by pikas significantly improved the grassland community status and soil physicochemical properties. Furthermore, Zhen et al. (2007) reported that climate change, especially global warming, which caused desertification, may be responsible for grassland degradation and the formation of black-soil-type degraded grassland in arid and semiarid areas. Although a majority of researchers consider the combination of natural element and anthropogenesis disturbance as a composite factor that can lead to the formation of black-soil-type degraded grassland (Li 1994, 2002; Liu et al. 1999; La and Liang 2000; Hui 2001). They explored the ways in which rodents, overgrazing and climatic change contribute differently to the degradation of the grassland. However, most of the authors emphasized one or two factors that contribute to the degradation of the black-soil-type alpine meadow ecosystem, and they neglected a basic problem that the alpine meadow ecosystem is an integrated ecosystem constituted of soil, plants and animals. Therefore, the formation mechanism and restorative measures of the black-soil-type degraded alpine meadow by utilizing the theory of recovery ecology may be a good method.

The recovery of black-soil-type degraded grassland

The idea of the recovery of degraded grassland has been explored by several researchers. To assess the grazing capacity toward grassland trend and degradation, a series of surverys were conducted at different grassland types and different degradation levels (Dong et al. 2002, 2003, 2005, 2008, 2011). In contrast, some researchers improve the grassland community by restraining grazing of livestock and/or decreasing activity of pikas. For example, Wu et al. (2009) found that that long-term fencing significantly improved above-ground vegetation productivity, restrained the development of noxious weed functional groups and improved soil quality. Lai et al. (2006) reported that aboveground biomass reached 4,510 kg/ha in the rodents-killing grassland (controlling the number of pikas), but it was 1,526 kg/ha in the degraded grassland. In addition, Li et al. (2012) studied the similarity of species composition between aboveground vegetation and soil seed banks in alpine grasslands at different degradation levels to assess the role of soil seed banks in restoring degraded grasslands. Shang et al. (2012) examined the effects of 3 years of fencing enclosure on soil seed banks, and Ma et al. (2011) also surveyed soil seed bank dynamics in the successional process of alpine wetland in the alpine region of the Qinghai-Tibetan Plateau. All of them attempted to find evidence to determine if the soil seed bank can serve as a potential method for the restoration of degraded alpine grassland and quantitate the contributed applicability of soil seed bank to the restoration of the aboveground vegetation in the degraded grasslands.

Besides these natural restorations of vegetation, other possible strategies for restoring of the heavily degraded alpine meadow in Tibetan Plateau are re-vegetation and re-establishment followed by appropriate management.

Compared to the non-reseeded meadow, Feng et al. (2010) indicated that *Elymus nutans* establishment after 3–7 growing seasons on heavily degraded alpine meadow has significantly improved soil quality and fertility. Wu et al. (2010) also found rebuilding of artificial grassland of *E. nutans* is central for restoration of vegetation productivity in black-soil-type degraded grassland. Shang et al. (2008) found that artificial seeding treatment can affect plant diversity and plant functional groups of grassland communities, which were in agreement with results from the above re-establishment experiments.

The purpose of this study was to determine the situation, main problems, formation mechanisms and recovery processes of the black-soil-type degraded alpine meadow using the theory of ecology and systemic science in combination with the theory of recovery ecology and sustainable development. This aim is in line with the need for western and sustainable developments and the need to explore synthetic management strategy which is a rehabilitation technology useful for restoring the black-soil-type degraded grassland ecosystem of the source region of Yangtze and Yellow Rivers.

Materials and methods

Study area

The source area of the Yangtze and Yellow Rivers lies in the hinterland of the Qinghai-Tibetan Plateau. It borders on southwestern Tibet Autonomous Region, abuts western Sichuan Province, Haixi Mongolian and Tibetan Autonomous Prefecture, Guide County of Hainan Tibetan Autonomous Prefecture and Tongren County of Huangnan Tibetan Autonomous Prefecture north of China (Fig. 1). The total land area is 366,400 km^2, including areas of 1.55×10^5 km^2 for the source region of the Yellow River, 2.08×10^5 km^2 for the source region of the Yangtze River, 4.06×10^4 km^2 for the source region of Lancangjiang and 4.76×10^4 km^2 for western Kekexili (Animal Husbandry Bureau of Qinghai Province, 2002). In terms of livestock, the number of horses, yaks (*Bos grunniens*) and Tibetan sheep are 145×10^5, 3.3×10^6 and 1.176×10^7, respectively. It is important to note that as the area of black-soil-type degraded grassland continuously extends in the region, soil erosion in the upper stream region

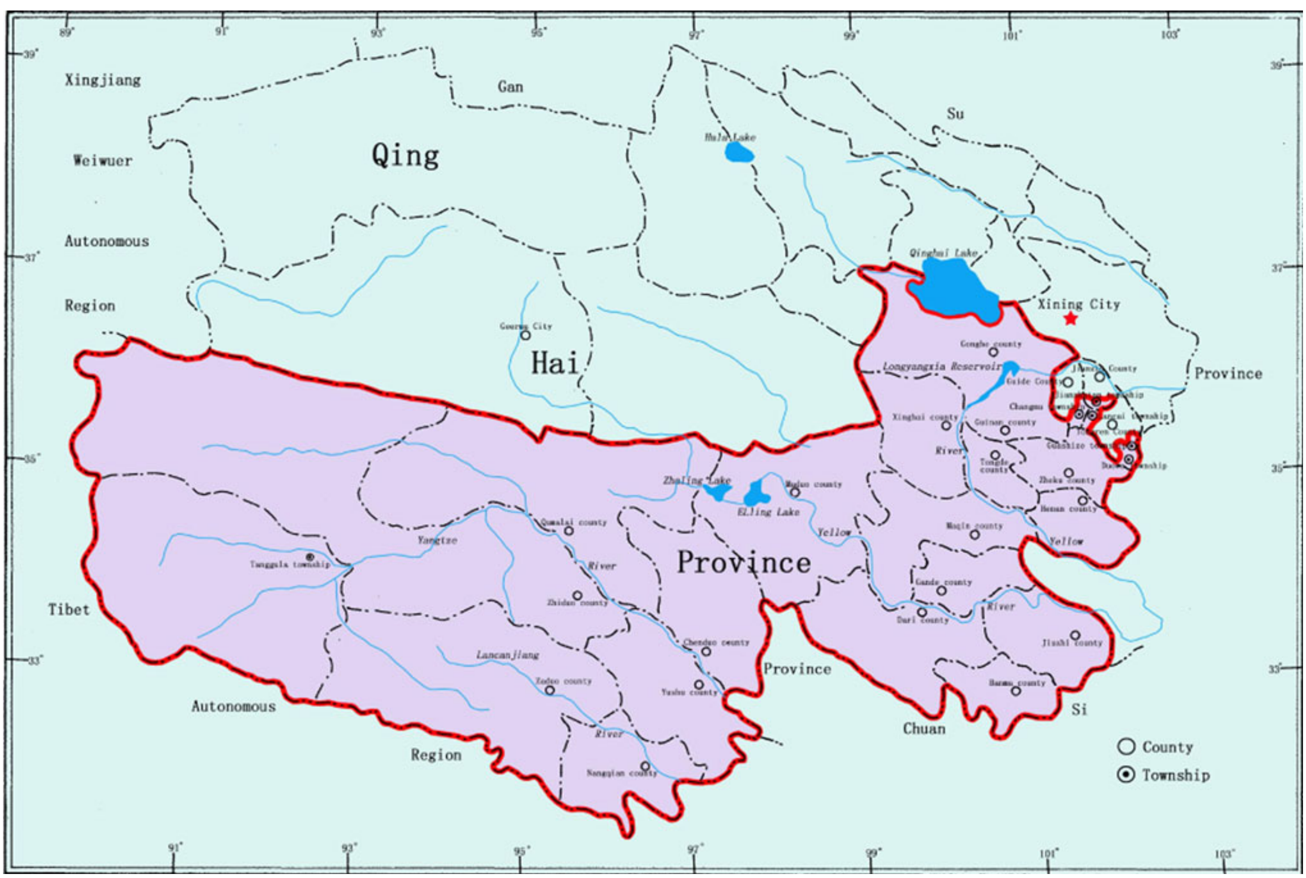

Fig. 1 Map of administrative division of Yangtze, Yellow, and Lancangjiang rivers headwaters region showing the location of the study sampling sites. It is located in the south of Qinghai Province, China

gradually becomes serious. According to statistics of the Qinghai Province Environmental Protection Bureau, every year, 9.03×10^{10} kg of soil and sand flows into the course of the rivers in the region which has been the most sensitive region in terms of ecological environments and the start-up region for climatic change in China. There are 18 counties and 6 townships around the source region of the Yangtze and Yellow Rivers. The experiment was conducted in Wosai Township of Dari County and Dawu Township of Maqin County, Guoluo Tibetan Autonomous Prefecture of Qinghai Province (Fig. 1), which is located 99°30′21″–100°33′42″N, 34°12′22″–33°49′19″E with an average elevation of 4,000 m above sea level. The Yellow River passes through the two counties. The landscape is characterized by large mountain ranges with steep valleys and gorges interspersed with relatively level and wide intermountain grassland basins. The climate of the research area is dominated by Southeast monsoon and high pressure of Siberia. It has a continental monsoon type of climate with severe and long winters and short cool summers. The average air temperature is −1.3 and −2.3 °C with maximum extremes of 24.6 and 23.2 °C, minimum of −34.5 and −32.5 °C, respectively, for Dari and Maqin counties. Average annual precipitation is 540 and 560 mm, respectively, 80 % of which falls in the short summer growing season from May to September. There is no absolutely fog-free period. The annual average sunlight is 2,331 h in Dari County and 2,533 h in Maqing County.

Study methods

Warm season pasture land was grazed from June to October, while cold season pastures were grazed from November to May the following year. Pasture production was determined by the following formula given by Lin et al. (2008):

$$P_n = \Delta B + L + G$$

where P_n is the net primary production, ΔB the increment of present forage yield of grassland in unit time, L the dead plant biomass and G is the plant biomass consumed by animals. This model is based on the method of sample plot survey, with five 100 m × 100 m blocks in each of the studied meadows. Ten zonal sampling plots (5 m × 8 m) and three random quadrats (0.5 m × 0.5 m) were established per plot in every block. The blocks were separated by approximately 500 m and the quadrats were randomly arranged in every sampling plot. Samples were taken annually in mid-August; the aboveground plant biomass in every quadrat was determined with harvest methods that consisted of clipping plant at the soil-surface level. The biomass was determined by weighing the plants after drying them at 80 °C for 48 h. Livestock feed intake was estimated using defecation, Cr_2O_3 and in vitro digestibility described by Lin et al. (2008):

$$\text{Defecation (g/day)} = \frac{Cr_2O_3 \text{ feeding (g/day)}}{Cr_2O_3 \text{ concentration in dung (\%, absolute dry)} \times 0.97},$$

$$\text{Feed intake (g/day)} = \frac{\text{Defecation (g/day)}}{1 - \text{digestibility (\%)}},$$

where defecation means amount of animal excretion every day, 0.97 is determination coefficient, digestibility means in vitro digestibility of plants were ingested by animal. Stocking rate was shown as sheep unit, which means the grassland could depasture the number of sheep. Carrying capacity theory was calculated as pasture yield, livestock intake and livestock number.

Desertification in the Tibetan Plateau grassland falls into five grades, on the criteria described by Ma and Lang (1998), Ma et al. (2002) and Shang et al. (2008), namely, original, slight, moderate, severe and very severe (black-soil land) desertification. The number and density of pikas (*Ochotona curzoniae*) were examined yearly in late August. There were five replications of every treatment area of 50 m × 50 m in each studied meadow. Each treatment was divided into four plots (each 25 m × 25 m) because of vegetation homogeneity and to facilitate the investigation. On the first day of survey, the number of all the caves were investigated and then buried with capping mass. The number was counted which was re-opened as active caves on the following day and buried again. All caves were surveyed between 12:00 and 14:00 for 3 days. At the end of the survey of caves, the pikas were captured until they no longer appeared and were released at their sites of origin after experiment. Density of pikas was calculated as the ratio of the number of active caves and the number of captured pikas.

Fenced enclosures have become an important method for re-establishing degraded grassland on the Tibetan Plateau. A 100 m × 100 m block for fenced treatment was selected. Within the 1 ha enclosure at each site, four replicate experimental plots of 400 m^2 (20 m × 20 m) were marked at random. Within each of these four plots, total plant cover, species composition and species cover were determined in mid-August at the optimum stage of plant development. The method was described in detail above. Besides the fenced enclosures, fertilization was used at a plot of 4 m × 5 m with diammonium phosphate (75 kg/ha) was applied as basal fertilizer. There are five repeated plots and they were separated by an interval of 5 m respectively. Furthermore, botulinum-C was applied to kill wild rodents in each of the different degraded meadow at a plot of 50 m × 50 m with five repeated treatment. In addition, metsulfuron-methyl and 2, 4-D-butyl were used as herbicides to control weeds in the studied meadow with the similar plots as deratization. All the treatment procedures were carried out via conventional methods (Dong et al. 2002, 2003). Analysis of variance was done using the GLM procedure (Statistical Analysis Systems Institute, Inc. 1994). When significant effects were obtained, differences between means were compared by the least squares of means (LSMeans) (Statistical Analysis Systems Institute, Inc. 1994).

Results and discussion

Relationship between animal grazing and degraded grassland ecosystem

In the Qinghai-Tibetan Plateau, livestock grazing, which is the most common form of land use, may cause changes in the spatial pattern of vegetation and soil properties. The state of natural grassland fresh yield, available natural grassland, number of animals, carrying capacity theory and over carrying capacity in the studied area are shown in Table 1. Based on review of literature and report of previous investigations conducted by the authors, in the source region of Yangtze and Yellow Rivers, as well as in other places in the Qinghai-Tibetan Plateau (Table 2), all grassland are seriously threatened by overstocking (Schaller 1998). For example, the rate of overstocking reached a range of 130 and 140 % in Hainan and Huangnan Tibetan Autonomous Prefecture, 30 and 60 % in Yushu and Guoluo Tibetan Autonomous Prefecture. In the source region of the Yangtze and Yellow Rivers, overstocking has reached 1.0×10^7 sheep units. Therefore, overstocking of livestock has been the main factor which led to the degradation of the grassland in this region. Overgrazing by livestock can alter plant communities, lower grassland conditions, destroy riparian area, reduce wildlife and wildlife habitat, cause soil erosion and loss of biodiversity. Each of these impacts has secondary or ecosystem-level effects (Rao and Casimir 1990; Miller 1997; Cao et al. 2003; Dong et al. 2005, 2011; Wu et al. 2009). Again, overgrazing can lead to severe trampling, accumulation and concentration of organic matter and chemicals from fecal matter and urine, increased sediment production, loss of infiltration, decrease of the organic matter or carbon and other associated consequences (Cao et al. 2003; Wu et al. 2010). By reducing the amount of total plant cover, overgrazing can both increase water run-off and soil erosion, decrease water infiltration. Within a particular ecosystem, the degree of the impact of overgrazing on the composition of plant community is a function of the intensity, frequency, seasonal timing, duration of overgrazing, level of selectivity and site characteristics, while the effect of overgrazing on plants is determined by temporal, spatial and vegetative characteristics of landscape (Holechek et al.

Table 1 Estimate of the degradation level of the alpine meadow in Qinghai-Tibetan Plateau, the source region of the Yangtze and Yellow Rivers

	Total local grassland area (hm^2)	Alpine meadow (hm^2)	Black-soil-type degraded grassland area (hm^2)
Yushu Prefecture	10,488,100	6,439,000	3,246,400
Guoluo Prefecture	6,753,700	4,280,900	2,074,000
Hainan Prefecture	2,836,200	2,310,700	175,400
Huangnan Prefecture	1,479,400	1,057,000	242,200
Tanggula Township of Ge'ermu City	1,101,900	451,700	0
Total	22,659,300	14,539,300	5,738,000

Table 2 The state of animals in Qinghai-Tibetan Plateau, the source region of the Yangtze and Yellow Rivers

	Fresh yield of natural grassland (kg/hm^2)	Available natural grassland (10^4 hm^2)	Animal unit (10^4 sheep units)	Carrying capacity theory (10^4 sheep units)	Over carrying capacity (10^4 sheep units)
Yushu Prefecture	1,363.05	956.982	748.81	571.78	177.02
Guoluo Prefecture	1,787.85	625.526	759.9	490.22	269.68
Hainan Prefecture	2,027.55	269.5193	552	239.54	312.45
Huangnan Prefecture	3,450.6	141.3813	457.23	213.85	243.38
Tanggula Township of Ge'ermu City	454.2	83.86	14.73	16.94	−2.21
Total		2,077.269	2,532.67	1,532.33	1,000.32

Table 3 Density of pikas and total number of holes in different stocking rates

Stocking rates	Average density (individual/hm^2)		Total no. of holes	
	Warm season pasture	Cold season pasture	Warm seasonal pasture	Cold season pasture
Ck	21^{Aa}	16^{Aa}	128^{Aa}	102^{Aa}
Light grazing	32^{Aa}	22^{Aa}	128^{Aa}	122^{Aa}
Moderate grazing	46^{b}	39^{b}	264^{Bb}	238^{Bb}
Heavy grazing	80^{Cc}	68^{Cc}	496^{Cc}	384^{Cc}
Correlation equation	$Y = 15.048X^2 - 3.4417X + 21.388$ ($R = 0.9980$)	$Y = 20.429X^2 - 8.3378X + 16.058$ ($R = 0.9999$)	$Y = 142.32X^2 - 117.09X + 124.46$ ($R = 0.9993$)	$Y = 31.5X^2 - 61.3X + 128.5$ ($R = 0.9978$)

In a list, if lowercase alphabet is same, the divergence is not significant, but if not the divergence is significant; however, if uppercase alphabet is different, divergence is extremely significant

1995). With the increase in the rate of stocking, the population density of pikas decreases. The correlation analysis showed that, in the relationship between stocking rates and average density of pikas, the total number of holes is the notable second degree polynomial regression ($P < 0.01$) (Table 3).

Relationship between climate and degraded grassland ecosystem

Climate data from Qinghai Meteorological Bureau related to Dari (1956–2002) and Maqing counties (1959–2001) indicated that average annual air temperature appeared to be in a rising trend, but annual precipitation decreased slightly with the passage of time in the source region of Yangtze and Yellow Rivers of the Qinghai-Tibetan Plateau (Fig. 2), which corresponds with the changes of global climate (Li et al. 2000; Xu et al. 2001; Yang et al. 2003). It is important to note that from the correlation analysis, the relationship between average annual air temperatures of the named years is significantly positive ($R = 0.4696$ in Maqing County; $R = 0.4328$ in Dari County, $P < 0.01$), while annual precipitation within each year had a slightly negative correlation ($R = -0.1162$ in Maqing County; $R = -0.0173$ in Dari County, $P > 0.05$). Many experts and scientists have paid close attention to the changes in climate of this region due to its unique climate and the nature of its environment. In addition, the region has recently been the most sensitive region in terms of ecological environments and the start-up region for changes in climate in China because a change in climate is a distinctive and important feature of a plateau region. Furthermore, the increase in the average annual air temperature in the past 50 years was 0.03–0.06 °C/10a globally, whereas it

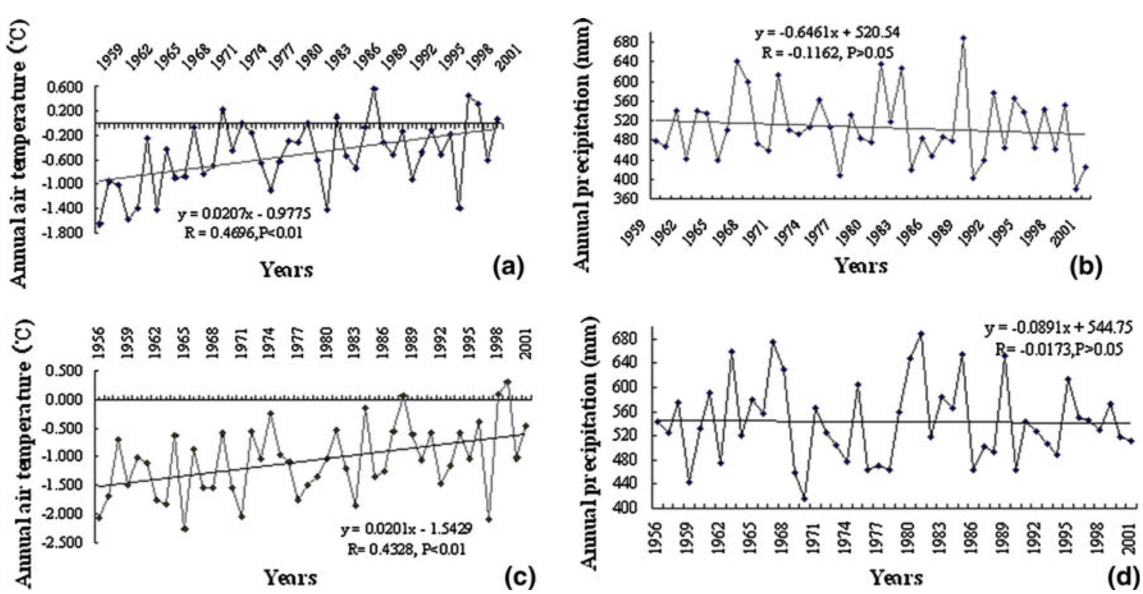

Fig. 2 Changes of average annual air temperature (**a**) and precipitation (**b**) in Maqing County and average annual air temperature (**c**) and precipitation (**d**) in Dari County of Guoluo Tibetan Autonomous Prefecture. The data were from the Qinghai Meteorological Bureau

was 0.16 °C/10a in the Qinghai-Tibetan Plateau, the source region of the Yangtze and Yellow Rivers, which is much larger than 0.04 °C/10a in other regions of China (Xu et al. 2001). Consequently, there appears to be some reports about effects of climate changes on the alpine meadow ecosystem and some forecasts for the Qinghai-Tibetan Plateau. When annual precipitation is relatively constant, the increase of air temperature cuts down aboveground biomass and height of plants, coverage of vegetation, postpones breeding stage, affects the ripening of seeds and reduces the number of dominant species (Qiu and Zhang 2000; Xu et al. 2001). Average annual air temperature and annual precipitation are likely to respectively increase by 1.5 or 4 °C and 0 or 20 % within 50 years; this will help enhance the aboveground biomass due to the greenhouse effects caused by CO_2 (Zhao and Chai 2000). If the average annual air temperature increases by 2 or 4 °C and annual precipitation increases by 10 or 20 % within 50 years, grassland production will reduce by 10 % or add by 1 % within 50 years in the alpine meadow ecosystem of the Qinghai-Tibetan Plateau (Li et al. 2000). The increase of air temperature can decrease and buffer the unfavorable effects of low air temperature on herbage to a certain degree in the alpine meadow. The increase in evaporation from the soil's surface and vegetation was more than the increase of precipitation; therefore, water could be the crucial factor needed for the growth of herbs. However, the increase in air temperature and the slight decrease in precipitation led to soil dryness which caused chaos in the functions of the grassland ecosystem and finally damaged and degraded the grassland ecosystem.

Formation mechanism of black-soil-type degraded grassland ecosystem

Animal and plants depend on soil to live in grassland ecosystems. Therefore, changes in soil structure can affect plants and animals. At the same time, it also limits the population of herbivores. On the contrary, the changes in the quantity of animals have large effects on plant community structure, plant nutrition and soil quality (Cao et al. 2003; Wu et al. 2010, 2011). Based on the available information from current investigation results, we found that the present state and distribution of livestock, rodents, soil, plants and climate in the degraded black-soil-type grassland were affected by a wide range of factors such as altitude range, district characteristics and meteorological conditions that are maintained for a long period of time. The dominant factors that speed up the formation of the black-soil-type degraded grassland included overstocking and climate change, though other factors such as rodent damage, wind erosion and erosion by rain also contributed (Shang and Long 2007; Shang et al. 2008). On the one hand, overgrazing which is caused by overstocking destroyed the primary vegetation (original vegetation) of the alpine meadow, while the increase in air temperature and slight decrease in precipitation led to soil dryness, decrease in the coverage, height and aboveground biomass of vegetation, loss of biodiversity, change in the communities of vegetation (including the decrease in the richness for species, diversity index and evenness index) and looseness of soil. Additionally, due to the effects of overgrazing and climate change on the grassland, the damage caused by rodents further intensified the degradation of the grassland; this progressive stage of degradation was not beneficial to the lives of plants and animals as the surface of the soil became loose. Moreover, with the action of wind erosion in the damaged area, the eroded sand and soil covered the grassland, leading to the decline of *Cobresia* species and the formation of barren ground under the pressure of wind and water erosion. Furthermore, the freeze and thaw caused the crack of the sod around the barren area (Yang et al. 2003) and made the roots around the crack to be detached from the soil, causing further degradation of the plant community, in addition to the action of wind and water erosion which destroyed the vegetation layer. Generally speaking, black-soil-type degraded grassland is formed first as a result of loss of vegetation via overgrazing, rodent damage, dry soil and the action of wind and water erosion. Then the final point of the degradation is the stripping of soil caused by freeze and thaw. Through field investigation and analysis data, we found that the vegetation of the grassland in Dari and Maqing counties is much more degraded than those northeast and south of the counties (Ma and Li 1999). In the higher and drier areas of Dari and Maqing counties, there appears some alpine desert grassland such as *Stipa aliena–Leontopodium nanum* grassland type, whereas alpine meadow forms the majority of the area and some shrub land are also distributed in a very limited area in the warm east and south region. There are more black-soil-type degraded grasslands in the northeast than in the southeast areas of the counties. All these showed that the desert climate in central Asia has a profound impact on the grassland of Dari and Maqing counties. As far as plants are concerned, the proto-*Cobresia* has the longest process of succession which reaches climax in a stable condition, but which cannot go through much decline in a short time without continued pressure from outside. Besides, with the inflation of population in the past 20 years, the influence of human activity has increased the progress of gradation of the grassland. Grassland abandonment which is a typical example of the consequences of human activity is exactly what became of the black-soil-type degraded grassland. According to the law of nature and theory of ecology, human beings can not only construct, protect and promote the self-adjustment and reproduction of grassland ecosystem but also damage grassland using scientific technology. Therefore, the formation of the black-soil-type degraded grassland is caused by a wide range of factors including human activity (Fig. 3).

Restorative measures of black-soil-type degraded grassland ecosystem

Recently, global focus has been on the restoration of degraded ecosystem and restoration ecology, but there has not been huge progress in restoring the degraded alpine meadow ecosystem of the Qinghai-Tibetan Plateau. Degradation is a regressive succession of grassland ecosystem resulting from the disturbance of human or natural factors. When the grassland ecosystem is disturbed by human or natural factors, its equilibrium state suffers displacement, leading to changes and hindrances in its structure and functions which form a destructive wave or vicious spiral named degraded grassland ecosystem. The restoration of degraded grassland ecosystem usually has two ways: one is natural restoration, while the other is rehabilitation or reclamation by human factors. In a degraded ecosystem, natural restoration is not overloaded, but reversible, while the other is overloaded, but reversible (Fig. 3).

Restorative measures for lightly and moderately degraded grassland ecosystem

Since 1998, every measure has been taken to explore suitable methods and ways to rehabilitate the black-soil-type degraded grassland in Dari and Maqing counties. Closure experiment was conducted continually for 6 years. Data were collected in late September every year. Other experiments for fertilizing (urea, 150 kg/hm^2), weeding (mixture weedicide which are applied for a patent, 75–100 g/hm^2) and use of rodenticide (biotoxin-D which was manufactured by the Qinghai bio-pharmacy factory) were conducted in the second year. These data were collected in late September in the third and fifth years; the data of the first year were used for contrast. Every measure that increases the total coverage, aboveground biomass of vegetation, the coverage and composition of good herbs and weeds can be considered (Table 4) (Ma et al. 2002). The decrease in stocking rate can increase the coverage, aboveground biomass, diversity and evenness of vegetation. Therefore, a decrease in stocking rates could rehabilitate lightly and moderately degraded grassland in certain periods. In addition, the optimal population structure of the livestock as well as their slaughter ages is also important for the rehabilitation of lightly and moderately degraded grassland.

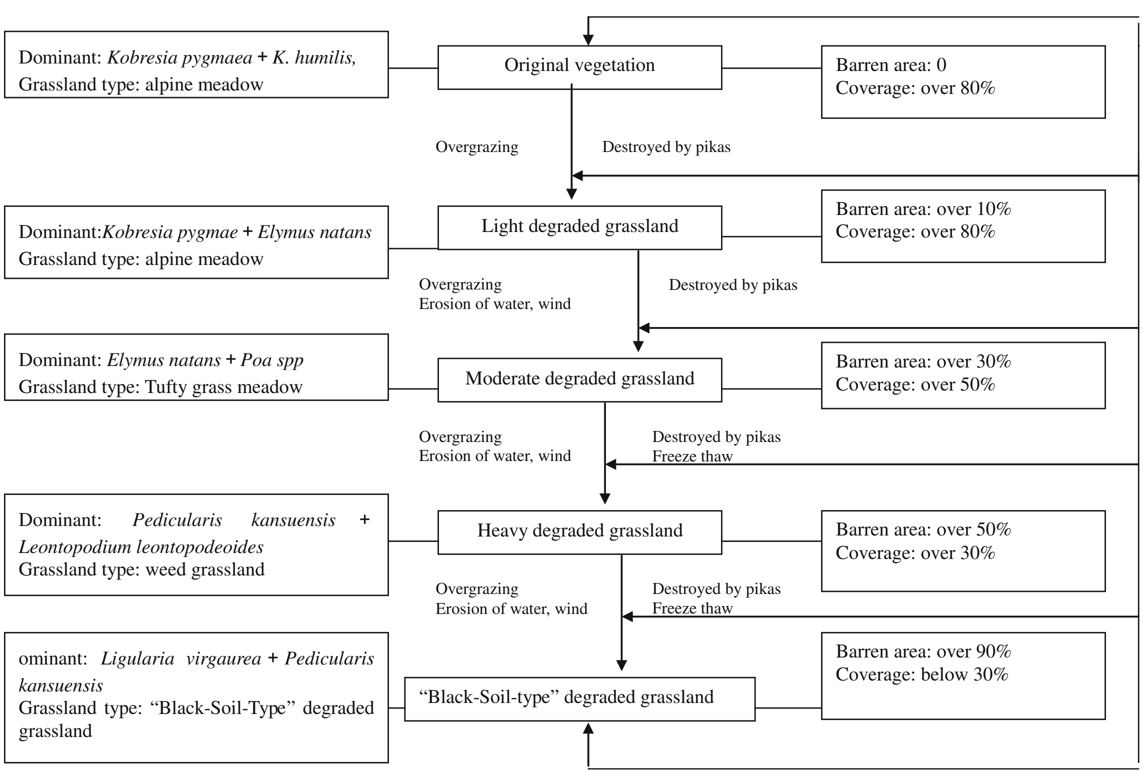

Fig. 3 Formation mechanism and converse succession series of "black-soil-type" degraded grassland ecosystem

Table 4 Effects of different rehabilitative measures on aboveground coverage, biomass and its composition

Measures	Degradation ranks	Closure time (year)	Aboveground biomass (g/m^2)	Total coverage (%)	Composition of aboveground biomass and coverage of different communities			
					Good herbs		Weeds	
					Composition (%)	Coverage (%)	Composition (%)	Coverage (%)
Closure of fence	Light degradation	1	318.5	76.5	59.8	59.5	40.2	30.5
		3	329.4	83.5	63.9	66.0	36.1	29.0
		4	346.8	85.0	63.8	65.0	36.2	27.5
		5	338.4	88.4	65.2	71.0	34.8	26.0
		6	346.1	93.5	66.9	79.5	33.1	20.0
	Moderate degradation	1	233.1	62.0	50.3	50.0	49.7	35.5
		2	248.1	70.5	57.8	55.5	42.2	32.5
		3	325.2	73.0	62.8	63.5	37.2	28.0
		4	339.8	85.0	63.6	65.5	36.4	26.0
		5	326.7	90.5	62.6	69.0	37.4	20.5
		6	313.8	90.0	65.1	66.5	34.1	18.0
Fertilization	Light degradation	1	298.7	75.0	60.8	67.5	39.2	38.0
		3	365.8	85.5	62.3	70.0	37.7	29.0
		5	365.6	90.0	63.8	76.5	37.2	25.0
	Moderate degradation	1	236.0	65.5	49.8	52.0	50.2	42.0
		3	278.6	76.8	55.8	64.0	44.2	32.5
		5	300.4	88.5	62.0	70.5	38	28.0
Weeding	Light degradation	1	290.5	72.0	55.9	65.0	40.1	35.0
		3	320.8	85.0	61.3	83.5	38.7	25.0
	Moderate degradation	1	220.8	68.0	48.5	54.0	51.5	40.0
		3	308.5	84.5	60.2	78.0	39.8	21.5
Use of rodenticide	Light Degradation	1	312.0	72.0	62.4	62.5	37.6	35.0
		3	332.0	81.5	68.3	70.0	31.7	31.5
	Moderate Degradation	1	215.0	65.0	56.0	55.0	44.0	36.5
		3	245.6	75.0	62.3	61.0	37.7	30.0

Rehabilitation measures for heavily and black-soil-type degraded grassland ecosystem

Most heavily and extremely degraded grasslands are distributed around habitation and spigot, which in the cold season is pastureland generally. Their coverage is mostly below 30 % and the ratio of weeds is 65–90 % generally. The main type of weeds found in such grasslands includes *Ligularia virgaurea*, *Pedicularis kansuensis*, *Oxytropis ochrantha*, *Heracleum millefolium*, *Potentilla anserine*, *Leontopodium nanum*, etc. They have no feeding value for animals. The degradation is overloaded, but not reversible. Therefore, they can be restored only by building artificial and semi-artificial grassland. The experiment carried out in the first 4 years showed that *Elymus antans*, *Elymus sibiricus*, *Festuca sinensis*, *Festuca rryloviana*, *Festuca kirilovii*, *Festuca rubra, Puccinellia tenuiflora*, *Hordeum violaceum* are very good in yield and can withstand winter. Besides, according to the theory of ecology and community restoration, the optimal combination of artificial and semi-artificial community of aforenamed herbage species was done. Results showed that *E. antans*, *E. sibiricus*, *F. sinensis*, *H. violaceum* were better as top grasses, while *F. rryloviana*, *F. kirilovii*, *F. rubra*, *P. tenuiflora* were better as bottom grasses for building artificial and semi-artificial grassland by scarification and replanting in the source region of the Yangtze and Yellow Rivers of the Qinghai-Tibetan Plateau (Fig. 3).

Black-soil-type degraded grassland is formed by a wide range of factors, including human activity. It progresses gradually from light to moderate degradation and finally from heavy to extreme degradation. It has been known that every grassland ecosystem has certain levels of fragility (Zhao et al. 1998). Similarly, the alpine meadow ecosystem around the Qinghai-Tibetan Plateau which is known for its harsh weather and harsh natural environments is more fragile compared to other grasslands in this area (Ma et al. 1999).

Grassland degradation is often simultaneously accompanied by soil degradation. Nitrogen and phosphorus cycles have been reported at length in the alpine meadow (Cao et al. 2003; Wu et al. 2010, 2011; Li et al. 2011). Therefore, the decrease of organic matter and total and available phosphorus could be a symbol of alpine meadow degradation (Dong et al. 2008; Wu et al. 2011; Li et al. 2011).

Although the fact that climate change causes the degradation of the alpine meadow has been disputed in model studies or theory analysis, the effect that climate change has on the community and coverage of vegetation and plant height in the Qinghai-Tibetan Plateau, is a known reality (Qiu and Zhang 2000; Xu et al. 2001). In addition, by analyzing the climate data of 43–46 years, it was very obvious that average annual air temperature increased gradually, while the annual precipitation decreased slightly (Fig. 2). Therefore, from biology, climate change can inevitably influence the growth and diversity of plants, community of vegetation, leading to an inevitable change in the fragility of the grassland ecosystem and an impairment of the stability of the grassland ecosystem which further degraded the grassland ecosystem.

Overstocking is the crucial factor for the formation of the black-soil-type degraded grassland in the source region of the Yangtze and Yellow Rivers of the Qinghai-Tibetan Plateau, where over 99 % of the grassland is seriously affected by overstocking. Overgrazing can alter plant communities, lower grassland conditions, destroy riparian area, cause soil erosion and loss of biodiversity (Miller 1997; Rao and Casimir 1990), which can cause the originally fragile grassland ecosystem to further degenerate, impairing the stability of the grassland ecosystem, finally leading to the degradation of the grassland ecosystem. Rodents, especially pikas, play significant roles in the degradation of the grassland by burrowing through the covering turf and gnawing at herbs. In the same vein, wind and water erosion, iterative freeze and thaw also play an active role in speeding up the degradation of the grassland (Shang and Long 2007). Also, with the inflation of population in the past 20 years, the role of human activity in the degradation of the grassland cannot be neglected.

The rehabilitation of black-soil-type degraded grassland ecosystem requires a long time. Depending on the extent of degradation, relevant measures could be taken such that the lighter the degree of degradation, the easier and quicker is the rehabilitation. The restoration of degraded grassland ecosystem usually has two pathways: one is natural restoration, while the other is rehabilitation or reclamation by human factors. The lightly and moderately degraded grassland ecosystem is reversible. Lightly and moderately degraded grassland can be rehabilitated by closing fences, weeding, fertilizing, use of rodenticide, decreasing stocking rate, optimizing the population structure of livestock as well as slaughter ages. As for heavily and extremely degraded grassland, they have no value for animals and their degradation is not reversible. Therefore, building artificial and semi-artificial grassland through furrow, scarification and replanting are the only ways by which they can be restored (Wu et al. 2010).

Overstocking exists everywhere, thus, yaks and Tibetan sheep graze in the Qinghai-Tibetan Plateau, the source region of the Yangtze and Yellow Rivers, including the area within Sanjiangyuan Natural Reserves. Such a situation is perhaps prevalent in most parts of Qinghai Province as well as other places of the Qinghai-Tibetan Plateau. The source region of the Yangtze and Yellow Rivers has been considered as the most sensitive region in terms of ecological environments, also as the start-up region for climatic changes in China, East Asia. Therefore, the rehabilitation of the black-soil-type degraded grassland ecosystem is especially crucial, requiring the close attention of government departments.

Conclusion and recommendations

The formation of "black-soil-type" degraded grassland ecosystem is result of comprehensive factors including human activity. Overgrazing by livestock caused by overstocking and climate change is a dominant factor; damage of rodents, especially pikas, by burrowing and covering turf, and gnawing at herbs speed up the forming process of "black-soil-type" degraded grassland, wind and rain erosion. Wind and rain erosion, iterative freeze and thaw play a role of activator, which further speeds up grassland degradation. Besides, with inflation of human population in recent 20 years, influence of human activity on grassland degradation cannot be neglected.

The rehabilitation of "black-soil-type" degraded grassland ecosystem needs a several decades time. According to the different degraded ranks, relevant measures should be adopted; the lighter the degraded degree, the easier and quicker is the rehabilitation. Restoration of degraded grassland ecosystem has commonly two paths: one is natural restoration and the other is rehabilitation or reclamation by human factors. The lightly and moderately degraded grassland ecosystem is reversible. Therefore, by fencing closure, weeding, fertilizing, using rodenticide, decreasing stocking rate, optimizing population structure stocked and slaughter ages, they can be rehabilitated. As for heavily extremely degraded grassland, they have been of no value to utilize and the degradation is not reversible. Therefore, only building artificial and semi-artificial grassland through furrow, scarification and replant can restore them. Therefore, the rehabilitation of "black-soil-type" degraded grassland ecosystem is especially crucial, which should be paid more attention to researches and practices of restoration technologies and measures.

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