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Research Article

Above- and Belowground Response along Degradation Gradient in an Alpine Grassland of the Qinghai-Tibetan Plateau

Grassland degradation is one of the worldwide ecological problems. The objective of this study was to assess the above- and belowground response of an alpine grassland along degradation gradient in the headwater areas of the Qinghai-Tibetan Plateau. Results showed that aboveground biomass, cover, and high quality herbage percentage presented a decreasing trend along degradation gradient. But, species number, species diversity, and evenness showed the maximum value in moderate degraded grassland, and the minimum value was appeared in the extreme degraded grassland. Similarity index was the maximum between original vegetation and light degradation grassland. And the similarity index between light degradation and moderate degradation, between original vegetation and moderate degradation were significantly different. Meanwhile, soil hardness, pH value, soil moisture, available nitrogen, available phosphorus, and available potassium, all showed the decreased trend along the grassland degradation gradient. Grassland degradation led to a decrease of soil physics and chemical properties. Our results predicted that there was also a degradation of soil properties when community structure and composition degraded along the grassland degradation gradient.

Keywords: Alpine meadow; Grassland ecosystem; Soil; Vegetation

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1 Introduction

Grassland degradation, which results in the decline of production and ecological function of grassland ecosystems due to structural degradation, is a global concern. Information on above- and belowground responses of grassland ecosystems during degradation process can improve our understanding on its function and potential succession direction to the disturbances. Alpine meadow is principal part composing nature ecosystem, which accounts for 90% of grassland area in the Qinghai-Tibetan Plateau, China. However, over half of grassland had degraded with different degrees, because unreasonable stocking rate and grazing system, unscientific feed and original manage and effects of increasing population, global climate changing and nature disaster on alpine meadow ecosystem. And grassland degradation seriously threatened on existence of herds and hindered sustainable development of animal husbandry in this region [1, 2].

Alpine grassland degradation driven by human disturbance and climatic change is limiting the sustainable development of ecological, social, and economic systems at local and regional levels in the headwater areas of the Qinghai-Tibetan Plateau [2]. Degradation had decreased the ecological function of alpine grassland in the headwater areas of the Qinghai-Tibetan Plateau. Many studies had reported the effects of rodent, overgrazing, climate changing on degraded grassland from the different sides [2–9]. Such degradation leads to depletion of vegetation cover and declines in biodiversity, which results in further degradation of soil physical and chemical properties such as soil bulk density, soil organic carbon (SOC), total nitrogen (N), and phosphorus (P) [4–7]. Information on responses of alpine grassland ecosystems can improve our understanding on its ecological function and potential succession progress along degradation gradient. So, we conducted this study to show the above- and belowground response of vegetation degradation in this area. Therefore, the objective of this study was to assess the response of aboveground community and belowground soil properties along grassland degradation gradient in the headwater areas of the Qinghai-Tibetan Plateau, China.

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Abbreviations: **AK**, available potassium; **AN**, available nitrogen; **AP**, available phosphorus; **ED**, extreme degradation; **HD**, heavy degradation; **LD**, light degradation; **MD**, moderate degradation; **OV**, original vegetation; **SOC**, soil organic carbon

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2 Materials and methods

2.1 Study area

This study was conducted at the Yangtze River and Yellow River source area, which lie in the hinterland of the Qinghai-Tibetan Plateau (Fig. 1). It borders on southwestern Tibet Autonomous Region, abuts on to western Sichuan Province, bounds with Haixi Mongolian and Tibetan Autonomous Prefecture, Guide County of Hainan Tibetan Autonomous Prefecture, Tongren County of Huangnan Tibetan Autonomous Prefecture north in China. The total land area is 3.66×10^5 km^2 including 1.55×10^5 km^2 in Yellow River source region, 2.08×10^5 km^2 in Yangtze River source region, 4.06×10^4 km^2 in Lancangjiang source region and 4.76×10^4 km^2 in western Kekexili [8, 9]. Besides, the number of horses, yaks, and Tibetan sheep are 145×10^5, 3.3×10^6 and 1.176×10^7, respectively. There are 18 counties and 6 townships in Yangtze River and Yellow River source region, which is located at 99°30′21″–100°33′42″N, 34°12′22″–33°49′19″E and the average elevation is 4000 m a.s.l. The climate of research area is dominated by Southeast monsoon and high pressure of Siberia. It has a continental monsoon type climate, with severe and long winters and short cool summers. The average air temperature is −1.3 and −2.3°C with extremes of maximum 24.6 and 23.2, and minimal −34.5 and −32.5°C, respectively. Average annual precipitation is 540 and 560 mm, respectively, 80% of which falls in the short summer growing season from May to September, and there is not the absolutely free-frog period [8, 9].

2.2 Study methods

This experiment included the changes of vegetation community and some of soil properties in the different degradation stages. Four degradation gradients (Tab. 1) were determined based on original vegetation (OV), according to the dominance and vegetation coverage of *Kobresia* spp. and good forage, the different degraded degree grasslands were divided into four grassland degradation types including light degradation (LD), moderate degradation (MD), heavy degradation (HD), and extreme degradation (ED) [10]. Vegetation community properties were investigated in yearly late August by five replications in every treatment, area of which is 50 m × 50 m. Soil samples were taken in August of the second year. The investigation of communities and measure of aboveground biomass were conducted by 30 replications in yearly late August, and area of quadrates is

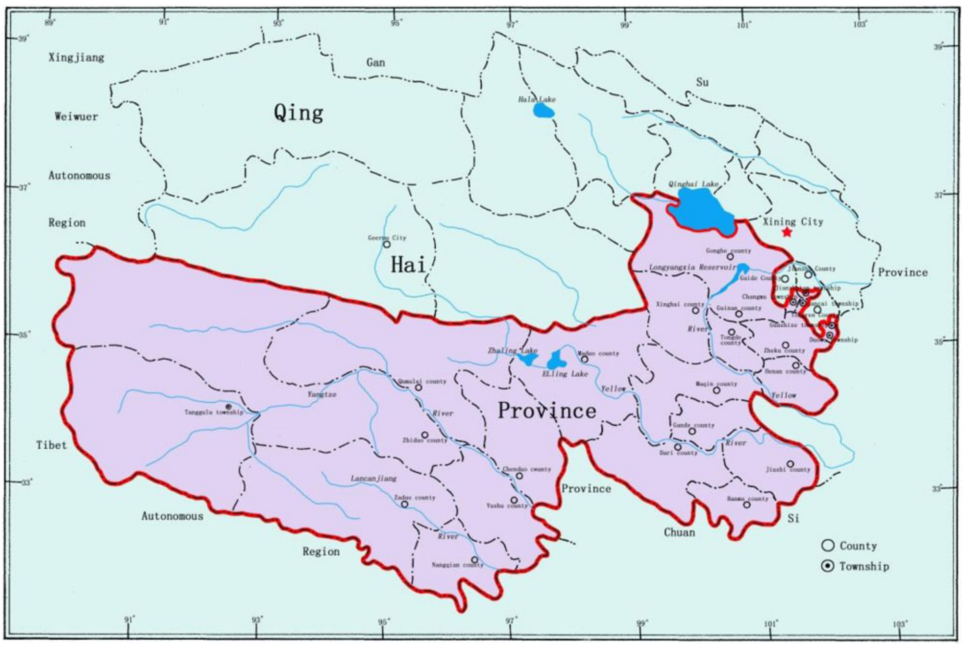

Figure 1. Map of administrative division of Yangtze, Yellow, and Lancangjiang rivers headwaters region showing the location of the study sampling sites. It is located in the south of Qinghai Province, China.

Table 1. Descriptions of community coverage, percentage of aboveground biomass to original vegetation, ratio of palatable forage and soil organic matter content for grasslands of four degraded gradients and original vegetation in this study

Degraded gradient	Coverage of vegetation (%)	Percentage of aboveground biomass (%)	Ratio of palatable forage (%)	Soil organic matter content (g/kg)
Original vegetation	80–90	100	70	>200
Light degradation	70–85	50–75	50–75	150–200
Moderate degradation	50–70	30–50	30–50	100–150
Heavy degradation	30–50	15–30	15–30	50–100
Extreme degradation	<30	<15	0	<50

50 cm × 50 cm for the different degradation grassland and other concerned trials. Indices of diversity, evenness, and similarity are three important parameters, which reflect community feature of vegetation from three different aspects. Indices of diversity and evenness were calculated according to:

$$H' = -\sum_{I=1} S(p_1 \log_2 p_i)$$

and:

$$J' = \frac{H'}{\log_2 S}$$

which are information index of Shannon–Wiener. H' is diversity index, p_i represents the ratio of a plant in all samples, J' denotes index of evenness, S represents no. of species. Similarity index was determined by:

$S_M = 2\sum \min(U_i^{(m)}, V_i)/\sum(U_i^{(m)} + V_i)$ of Greg–Smith. S_M denotes similarity index, $U_i^{(m)}$ is richness of vegetation community in different degraded grassland. "i" represents very communities of different degrading ranks ($i = 1, 2, 3, 4$). V_i is the richness of original vegetation (aboveground biomass). m is different degrading gradient. $U_i^{(m)}$ denotes aboveground biomass with degrading gradient. Obviously, S_M is between 0 and 1. With the aggravation of degradation, coverage of vegetation, aboveground biomass and percentage of high quality forage have a dropping trend. Number of species, diversity index, and evenness index reached to the maximum in moderate degradation grassland, the minimum in extreme degradation grassland, and the percentage of aboveground biomass for high quality forage reduces abruptly, which showed that the moderate degradation grassland have no fit to grazing for animal, if it does, grassland would continue degradation [8, 9]. Dry matter for aboveground and soil was determined by oven drying at 80°C for 24 h.

The topsoil hardness and moisture of weight ratio were determined by ordinary gravimetric measurement [11]. Meanwhile, we collected five soil samples from each soil depths (0–10 and 10–20 cm) of each quadrat in a simple random pattern by bucket auger, then fixed soil samples of each sampling quadrat at the same depths [11]. Fifteen mixed soil samples were used to analyze soil chemical properties in each soil depth of each quadrat [11]. All soil samples were air-dried and then passed through a 0.14 mm sieve. Soil pH value was determined using a soil/water ratio of 1:5; soil organic carbon content (SOC) in the soil samples was measured using the $K_2Cr_2O_7$ method [11]. Soil available nitrogen (AN), available phosphorous (AP), and available potassium (AK) content were measured in laboratory, by the methods of Wu et al. [4, 5]. The content of each nutrient trait calculated by the proportions of SOC, AN, AP, and AK account for per soil dry weight [11].

Data of soil nutrition were provided by the Qinghai Academy of Animal and Veterinary sciences. Analysis of variance was done using the GLM procedure. When significant effects were obtained, differences between means were compared by the least squares means.

3. Results and discussion

3.1 Plant communities response to grassland degradation gradient

Aboveground biomass, coverage, species number, species diversity, evenness, and percentage of high quality herbage all were significantly different among grasslands of different degradation gradients (Tab. 2). Aboveground biomass (OV, 152.4, LD, 103.4, MD, 80.2, HD, 68.9, and ED, 15.9 g/m^2), coverage (OV, 94, LD, 85, MD, 65, HD, 41, and ED, 25%), and percentage of high quality herbage (OV, 82.16, LD, 72.08, MD, 31.06, HD, 18.80, and ED, 6.20%) showed a decreased trend along degradation gradient. But, species number (OV, 32, LD, 40, MD, 44, HD, 26, and ED, 16), species diversity (OV, 2.86, LD, 3.19, MD, 3.31, HD, 2.43, and ED, 1.63), and evenness (OV, 0.57, LD, 0.60, MD, 0.61, HD, 0.52, and ED, 0.39) showed the maximum value in MD grasslands, and the minimum value were appeared in the ED grasslands.

Disturbance has been identified as an important mechanism that makes possible the maintenance of species diversities in plant communities [12, 13]. High-intensity grazing resulted in heavily degradation of alpine meadow communities of the Qinghai-Tibetan Plateau represents a disturbance that has brought about notable ecological degradation [14]. Additionally, grazing disturbance can alter the relationship between seed size and dominance for coexistent species within alpine grassland communities [15] and species richness and total individual density reached their maximum in the meadow community with moderate grazing intensity. Moderate grazing disturbance can increase species diversity by increasing individual densities [15, 16].

Similarity index can reflect the divergence between communities accurately. Similarity index is the maximum between original vegetation and light degradation grassland (0.8001), and then between light degradation and moderate degradation (0.5998), between original vegetation, and moderate degradation (0.5445; Tab. 3), which indicates that species diversity composition showed significant differences for communities of different degradation grassland or different succession stages in this study. The same

Table 2. Descriptive statistics for plant communities feature of different degraded grassland in Yangtze River and Yellow River source region in Qinghai-Tibetan Plateau

Degraded gradient	Aboveground biomass (g/m^2)	Coverage (%)	Number of species	Diversity index	Evenness index	Percentage of high quality herbage (%)
Original vegetation	152.40^{Aa}	94^{Aa}	32^{a}	2.86^{Ba}	0.57^{Aa}	82.16^{Aa}
Light degradation	103.40^{Cb}	85^{Aa}	40^{Bb}	3.19^{Bb}	0.60^{Aa}	72.08^{Aa}
Moderate degradation	80.20^{Cb}	65^{b}	44^{Bb}	3.31^{Bb}	0.61^{Aa}	31.06^{Bb}
Heavy degradation	68.90^{Cc}	41^{Bc}	26^{c}	2.43^{a}	0.52^{Ab}	18.80^{Bc}
Extreme degradation	15.90^{Dd}	25^{Bd}	16^{Dd}	1.63^{Cc}	0.39^{Bc}	6.20^{Dd}

In a list, if minuscule alphabet is same, the divergence is not significant, on the contrary, divergence is significant, and if capital is different, divergence is extremely significant.

Table 3. Similarity indices for vegetation diversity of different degraded grassland in Yangtze River and Yellow River source region in the Qinghai-Tibetan Plateau

Degraded gradient	Original vegetation	Light degradation	Moderate degradation	Heavy degradation	Extreme degradation
Original vegetation	1.0000				
Light degradation	0.8001	1.0000			
Moderate degradation	0.5445	0.5998	1.0000		
Heavy degradation	0.3201	0.4209	0.3365	1.0000	
Extreme degradation	0.2369	0.2980	0.1739	0.2036	1.0000

conclusion was also reported by Wu et al. [17] that plant species composition similarity were decreased with grassland degradation compared to original vegetation. So, these showed that grassland degradation had affected plant species diversity compositions.

Additionally, grassland became heavily degraded, plant species composition and diversity changes accordingly, the proportion of more palatable plants such as grasses and grass-like plants also decreased with degradation degree. And plant functional group types that were dominated either by grasses or by forbs played an important role in determining the relationships of aboveground vegetation and belowground soil chemical properties, the higher proportion of more palatable species predicted a higher soil nutrient availability in alpine grassland [4, 6].

3.2 Soil response to grassland degradation gradient

Grassland degradation accompany with occurrence of soil degradation synchronously. Therefore, grassland degradation can lead to changes of physics characteristics and nutrition factors of soil (Tab. 4). With the increase of degradation degree, hardness of soil decreased, and their divergence is extremely significant ($p < 0.01$), and on the contrary, pH value increase, but their divergence is not significant in the same depth of soil ($p > 0.05$). As for water contents, the difference between extreme degradation and other degradation ranks is significant in the depth of 0–10 cm ($p < 0.05$), but it is not significant in the depth of 10–20 cm ($p > 0.05$). Contents of AP have a decrease trend, the different between original vegetation and other degradation ranks is significant n the depth of 0–10 cm ($p < 0.05$), and it is also significant between light and moderate degradation and other degradation ranks in the depth of 10–20 cm ($p < 0.05$). But AK has a dropping trend in the depth of 0–10 cm without certain rule in the depth of 10–20 cm. Contents of water and AN are maximum in light and moderate degradation ranks in the depth of 0–10 and 10–20 cm. And the AN content is significantly different between heavy and extreme degradation and other degradation ranks in the depth of 0–10 cm ($p < 0.01$) and 10–20 cm ($p < 0.05$).

Grassland degradation significantly changed soil moisture, altered soil physical, and chemical properties. Available nutrition contents were related to the mineralization velocity of soil, the number and decomposing capacity of microorganism, the amount of assimilation for plants, and excretion for animals [3, 7, 18]. With the increase of degradation degree, the coverage of vegetation reduced, which leads to the decrease of microorganism number, the mineralization velocity of soil, the decrease of assimilation for plants and excretion for animals, therefore, soil nutrition contents appeared decreasing trend. As for light and moderate degradation, it may relate to low C/N, slow velocity of mineralization and the little amount of assimilation for plants, because degradation of the alpine grassland had a positive feedback effect on CH_4 and CO_2 emissions and the carbon loss in soil [19].

Degraded grassland is formed comprehensively by lots of factors including human activity and climate change, and it is gradually formed from light gradation to moderate, heavy, and then extremely degraded grassland. Grassland degradation can lead to changes of soil physical and chemical properties. Therefore, grassland community degradation was accompanied with occurrence of soil degradation synchronously, and the decrease of soil quality and nutrient properties could be as symbol of alpine meadow degradation.

Table 4. Soil physics characteristics and nutrient properties (Mean ± SD) in different degraded grasslands in Yangtze River and Yellow River source region in the Qinghai-Tibetan Plateau

Degraded rank	Depth (cm)	Hardness (kg/m^3)	pH value	Soil moisture (%)	Available N (ppm)	Available P (ppm)	Available K (ppm)
Original vegetation	0–10	4.356 ± 2.12^{Aa}	6.30 ± 2.34^{a}	23.98 ± 13.98^{a}	216.82 ± 123.09^{Aa}	0.41 ± 0.21^{a}	189.82 ± 66.09^{a}
	10–20		6.56 ± 2.97^{b}	8.98 ± 4.01^{a}	109.73 ± 45.29^{a}	0.83 ± 0.33^{a}	126.32 ± 44.98^{a}
Light degradation	0–10	3.213 ± 1.76^{Ab}	6.40 ± 3.21^{a}	25.69 ± 11.09^{a}	325.41 ± 122.09^{Ab}	0.33 ± 0.17^{b}	180.32 ± 60.07^{a}
	10–20		6.59 ± 3.45^{b}	10.08 ± 3.98^{a}	268.43 ± 165.65^{b}	0.60 ± 0.32^{b}	125.98 ± 45.67^{a}
Moderate degradation	0–10	2.566 ± 1.25^{b}	6.49 ± 2.21^{a}	25.01 ± 10.92^{a}	225.38 ± 109.08^{Aa}	0.29 ± 0.11^{b}	165.23 ± 79.75^{a}
	10–20		6.62 ± 3.09^{b}	8.99 ± 2.99^{a}	150.81 ± 43.57^{a}	0.56 ± 0.27^{b}	123.02 ± 56.04^{a}
Heavy degradation	0–10	1.338 ± 0.4^{Cc}	6.56 ± 2.98^{a}	22.23 ± 11.89^{a}	149.63 ± 60.09^{Bc}	0.29 ± 0.11^{b}	185.62 ± 101.09^{a}
	10–20		6.67 ± 2.23^{b}	8.02 ± 2.99^{a}	199.9 ± 98.01^{b}	0.43 ± 0.22^{c}	169.56 ± 77.90^{b}
Extreme degradation	0–10	0.229 ± 0.12^{Cd}	6.64 ± 3.01^{a}	19.99 ± 5.87^{b}	100.32 ± 33.31^{Bc}	0.26 ± 0.11^{b}	146.10 ± 78.45^{a}
	10–20		6.83 ± 3.45^{b}	7.98 ± 3.13^{a}	119.1 ± 35.76^{a}	0.19 ± 0.09^{d}	171.32 ± 88.78^{b}

In the same list and depth for soil, if minuscule alphabet is same, the divergence is not significant, on the contrary, divergence is significant, and if capital is different, divergence is extremely significant.

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