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RESEARCH ARTICLE

Using comprehensive and sequential vegetation classification system to predict the influence of climate change on vegetation succession of alpine grassland of Qinghai Plateau

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Abstract Distribution of grassland vegetation is highly associated with climatic conditions and varied with climatic change. The tendency of climatic changes on Qinghai Plateau was analyzed, based on the meteorological data from 1961 to 2007 collected from 50 meteorological stations distributed throughout the whole plateau. The vegetation distribution of alpine grassland under past and future climatic change was estimated by using the approach of Comprehensive and Sequential Classification system. Results show that the climate varied greatly before and after 1987. The temperature increased 0.16°C/10a before 1987 and 0.64°C/10a after 1987. The precipitation increased 0.14 mm/10a before 1987 and 3.92 mm/10a after 1987. There were 12 types of grassland vegetation between 1961 and 1987, while there were 11 types of grassland vegetation between 1988 and 2007 on the Plateau. When climatic warming continued with CO_2 doubling in the future, the vegetation of alpine grassland will shrink into nine types.

Keywords comprehensive and sequential classification, grassland type, climate condition in the future

1 Introduction

Global warming affected the natural ecosystem directly and indirectly now (Houghton et al., 2001). Many evidences showed that climate change had affected the all kinds system of nature, for example, shrunken glaciers (Shi et al., 2005), melted permafrost (Osterkamp et al., 2000; Izrael et al., 2002; Nelson, 2003), and prolonged growth season of vegetation in middle-high latitude (Zheng et al., 2002). It was reported that Qinghai-Tibetan Plateau, the third pole of the world located in Western China, was more sensitive to climate warming (United Nations Framework Convention on Climate Change, 1992). Many researches revealed that the increase of temperature on Qinghai-Tibetan Plateau was higher than that of the whole nation. Different from the temperature, precipitation on Qinghai-Tibetan Plateau changed with great different both at temporal and spatial scales, i.e., increasing in some areas and some years and decreasing in some areas and some years. It is important to understand the effects of climatic changes on the alpine ecosystems and the adaptation of alpine ecosystems to climatic changes (McCarthy et al., 2001; van Minnen et al., 2002; Fuhrer, 2003; Hitz and Smith, 2004). As the largest ecosystem on the Qinghai-Tibetan Plateau, the alpine grassland should be emphasized in the study of ecosystems' adaptation to the climatic change. In this paper, the effects of climatic change on the distribution pattern of the alpine grassland vegetation and the adaptation strategies of alpine grassland vegetation to the climatic change on the eastern Part of Qinghai-Tibetan Plateau were estimated based on Comprehensive and Sequential Vegetation Classification System forwarded by Ren et al. (1980) and modified by Hu (1994), Hu and Gao (1995), so as to

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optimize the management systems of alpine grassland on the Qinghai Plateau under the setting of climatic change.

2 Data source and methods

2.1 Data source

The vegetation data were obtained from different various scientific publication, reports, and monographs related to this study, such as Grassland Resources in Qinghai (1987), and were cross-checked via on-the-spot investigation and remote sensing image interpretation. Climatic data used for Comprehensive and Sequential Vegetation Classification System analysis in this study including daily mean temperature and precipitation from 1961 to 2007, and the averages of climatic variables (precipitation and temperature) over 30 years from 1971 to 2000 were collected from the 50 national meteorological stations located within whole Qinghai Plateau.

2.2 Methodology

The possible change of alpine grassland vegetation under the climatic changes was estimated by using modified Comprehensive and Sequential Classification System, in which the moist index (*K*) was regarded as the key factor determining the distribution of grassland vegetation (Ren et al., 1980; Hu and Gao, 1995). The calculation for the *K* is shown in the following formulas:

$$K = R/0.1\sum_{i=1}^{n} T_i\,, \tag{1}$$

where K is the moist index; and R, n, and T_i represent the mean annual rainfall (mm), days with > 0°C mean daily temperature in a year, and the mean daily temperature on day i (°C), respectively.

The value of *K* calculated from the above formulas was used to project the grassland vegetation type on the map of Comprehensive and Sequential Classification System, which was developed by Ren et al. (1980) and modified and digitalized by Hu and Gao (1995).

3 Results and discussion

3.1 Tendency of climate change on Qinghai Plateau since 1961

Using the average of climatic data from 1971 to 2000 as the baseline, the tendency of annual mean temperature and annual precipitation of whole province were estimated and presented in Figs. 1 and 2. It was found that the annual mean temperature had an increasing trend, with increase rate of 0.35°C/10a, which is far higher than 0.13°C/10a, the average increase of global temperature, and 0.16°C/10a, the average increase of temperature in China in past 50 years (see Fig. 1). In 1987, there was a clear shift of temperature from the under-average to the above-average; meaning, there were cooling years from 1961 to 1987 (with 0.16°C/10a below the average) and warming years from 1988 to 2007 (with 0.64°C/10a above the average). In addition to temporal difference, there were spatial differences of temperature change on the Qinghai-Tibetan Plateau (data were not shown).

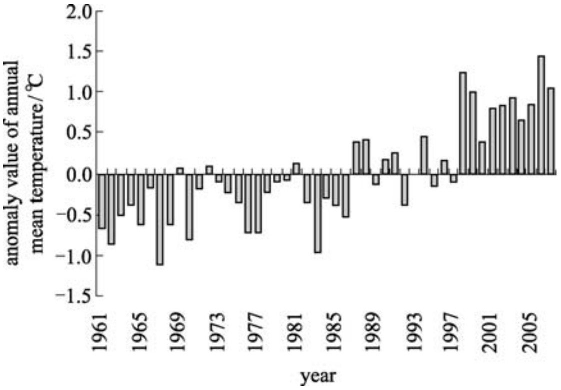

Fig. 1 Anomaly change of annual mean temperature from 1961 to 2007 in Qinghai

In contrast to the temperature, no clear tendency of decrease or increase was observed on the precipitation in past 50 years. However, there were great variations of annual precipitation among years with change rate of 0.14 mm/10a before 1987 and 3.92 mm/10a after 1987 (see Fig.2). Moreover, there were big variations of annual precipitation at the spatial scale on the Qinghai-Tibetan Plateau (data were not shown).

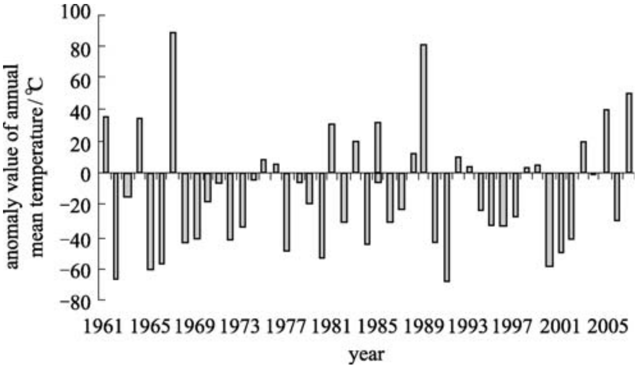

Fig. 2 Change rate of precipitation anomaly from 1961 to 2007 in Qinghai

3.2 Change of alpine vegetation distribution with past climate change

Based on the metrological data, the potential grassland vegetation was estimated by using the Approach of Advanced Comprehensive and Sequential Classification System. As there was a transit boundary of climatic change in 1987, the vegetation dynamics were estimated in two periods, before and after 1987. Figure 3 showed that the annual accumulated temperature of > 0°C varied i.e., the annual accumulated temperature of > 0°C on the whole Qinghai Plateau increased dramatically after 1987. As a result, the moisture index varied greatly at temporal scale (before 1987 and after 1987). In addition, spatial variations of the moisture index were found due to the difference of climatic changes on whole Plateau. The climate data collected from the study sites show that the annual accumulated temperature of > 0°C ($\sum\theta$) increased, while the moisture index decreased in most areas since 1987 (see Fig. 3). The climate data of the selected case sites show that the annual accumulated temperature of > 0°C ($\sum\theta$) in Geermu, Gangcha, and Maduo increased to 200.25 mm, 103.98 mm, and 78.47 mm, respectively, and the moisture index decreased to 0.018, 0.112, and 0.405, respectively (see Table 1).

With the climatic change, vegetation type and distribution on the Plateau changed accordingly at both the temporal and the spatial scales. Before 1987, there were 12 vegetations types distributed on the whole Plateau: frigid per humid rain tundra. alpine meadow, cold temperate-arid montane semidesert, Cold temperate-per humid cold conifer forest, Cool temperate-arid temperate zonal semidesert, Cold temperature-semiarid montane steppe, Cool temperate-extra-arid temperate zonal desert, Cold temperate-subhumid montane meadow steppe, Cold temperate-humid montane meadow, Cool temperate-semiarid temperate typical steppe, Cold temperate-extra-arid montane desert, Cool temperate-humid forest steppe. deciduous broad leaved forest, and Cool temperature-subhumid meadow steppe (see Fig. 4).

After 1987, 11 vegetation types distributed on the Qinghai Plateau: Cool temperate-semiarid temperate typical steppe, Frigid per humid rain tundra .alpine meadow, Cool temperate-extra-arid temperate zone desert, Cold temperate-per humid cold conifer forest, cold temperate-arid montane semidesert, Cool temperate-arid temperate zonal semidesert, Cold temperate-extra-arid montane desert, Cold temperature-semiarid montane steppe, Cold temperate-humid montane meadow, Cool temperature-subhumid meadow steppe, Cool temperate-humid forest steppe, and deciduous broad leaved forest (see Fig. 5). Comparatively, there were clear difference of vegetation types and distribution between two periods, 1961–1987 and 1988–2007.

3.3 Change of alpine vegetation distribution with future climate change

It is well known that the global warming is highly associated with CO_2 doubling, which may indirectly influence the distribution and composition of alpine vegetation on the Plateau in the future. It is estimated that the annual mean temperature on west Qinghai Plateau will rise to 2.5°C–2.6°C and that on the east Qinghai will increase to 2.8°C–3.0°C when CO_2 is doubled (Gao et al., 2003).

Correlation analysis based on climatic data collected from fifty meteorological stations of Qinghai showed that there were good correlation between annual mean temperature and annual accumulated temperature of > 0°C, with correlation coefficient of 0.98 ($p < 0.01$).

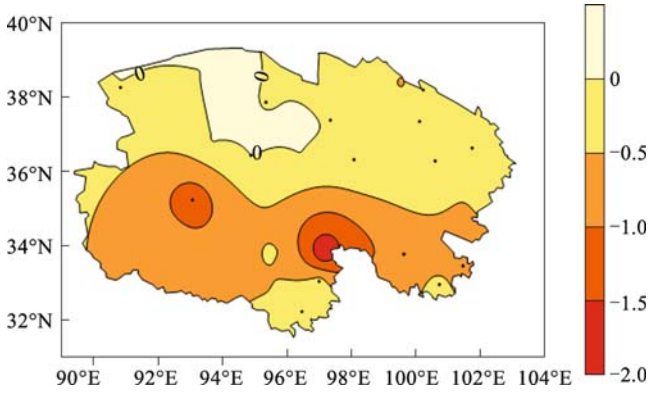

Fig. 3 Moisture index difference pre and post 1987

Table 1 Change rate of annual accumulated temperature > 0°C and the moisture index in study sites before and after 1987

area	Geermu		Gangcha		Maduo	
period	1961–1987	1988–2007	1961–1987	1988–2007	1961–1987	1988–2007
$\sum\theta$ (/10a)	90.1	200.25	−18.59	103.98	−28.5	78.47
moisture index (/10a)	0.004	−0.018	0.093	−0.112	0.292	−0.405

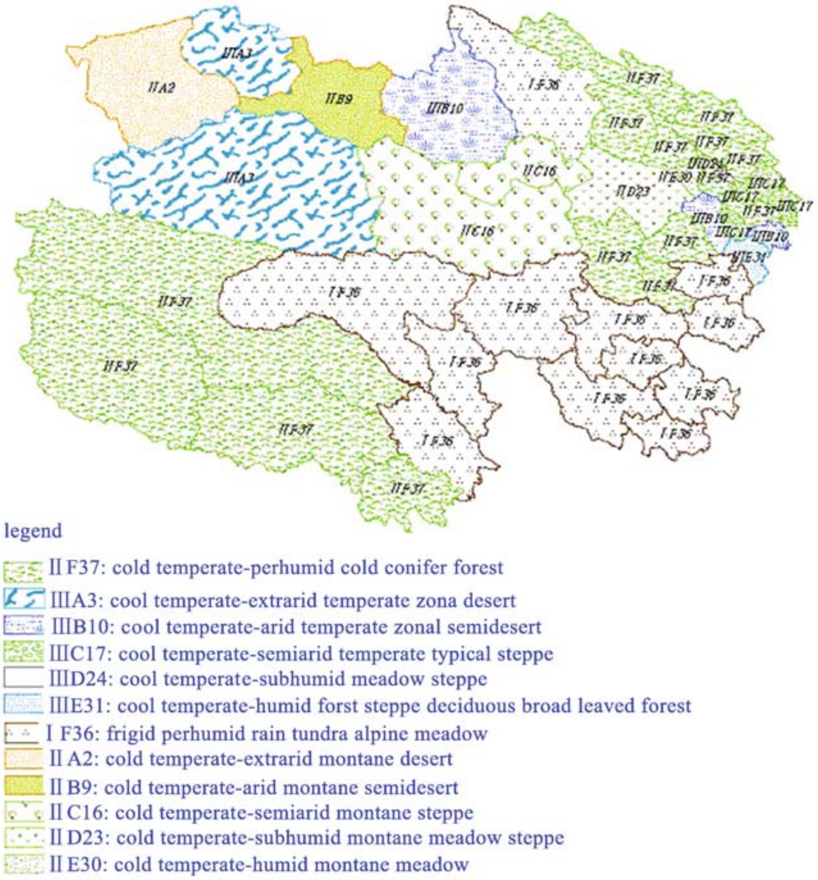

Fig. 4 Grassland type distribution of Qinghai before 1987

Therefore, the annual accumulated temperature of $>0°C$ can be estimated from the annual mean temperature using the following formula:

$$Y = 1534.355 + 216.227t, \quad (2)$$

where Y is annual accumulated temperature of $>0°C$, and t is the annual mean temperature. Based on this formula, the annual accumulated temperature of $>0°C$ on the Qinghai Plateau associated with CO_2 doubling can be obtained and presented in Fig. 6. Coupling with the change of precipitation (around 20% increment in the future) predicted by many scholars (Gao et al., 2003), the change of the moisture index can be assumed and shown in Fig. 7.

When the moisture change with doubled CO_2 following the trend we predicted, the changes of vegetation distribution can be estimated by using Advanced Comprehensive and Sequential Classification System as follows: frigid per humid rain tundra. alpine meadow, cold temperate-per humid cold conifer forest, warm temperature-arid warm temperature zonal semidesert, warm temperature-semiarid warm temperature zonal typical steppe, cool temperate-moisture needle .deciduous broad leaved mixed forest, cool temperate-arid temperate zonal semidesert, cool temperate-extra-arid temperate zone desert, cool temperate-humid forest steppe .deciduous broad leaved forest, cool temperature-subhumid meadow steppe, etc. (see Fig. 8).

4 Conclusions

1) The annual mean temperature on the Qinghai increased by 0.35°C/10a from the year of 1961 to 2007, while the annual precipitation did not change greatly.

2) The climatic change varied at both temporal and spatial scales. The climate became warmer and wetter after 1987 than that before 1987.

3) When the CO_2 is doubled in the future, the temperature will increase greatly, while the precipitation will remain nearly unchanged. As a result, the vegetation distribution of alpine grassland will change accordingly.

4) With the climatic warming, the vegetation of alpine grassland on the Qinghai Plateau will decrease from 12 types before 1987 to 11 types after 1987.

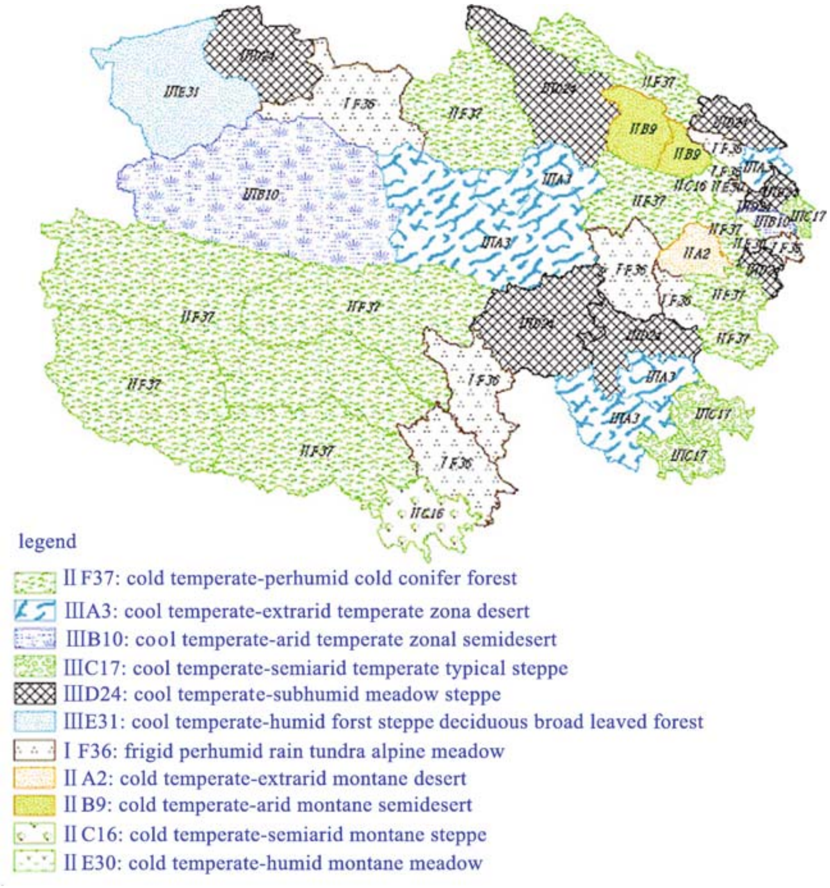

Fig. 5 Grassland type distribution of Qinghai after 1987

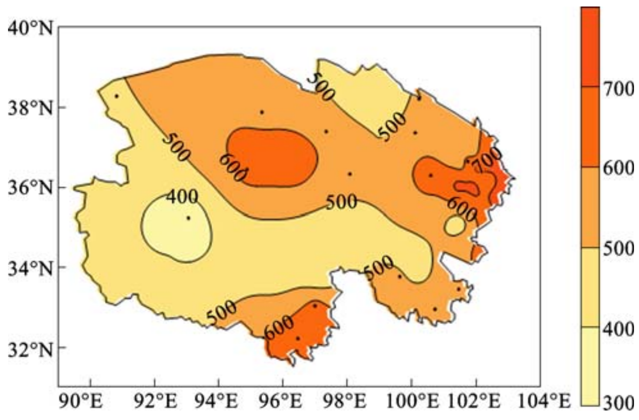

Fig. 6 Accumulated temperature difference pre- and post-doubled CO_2

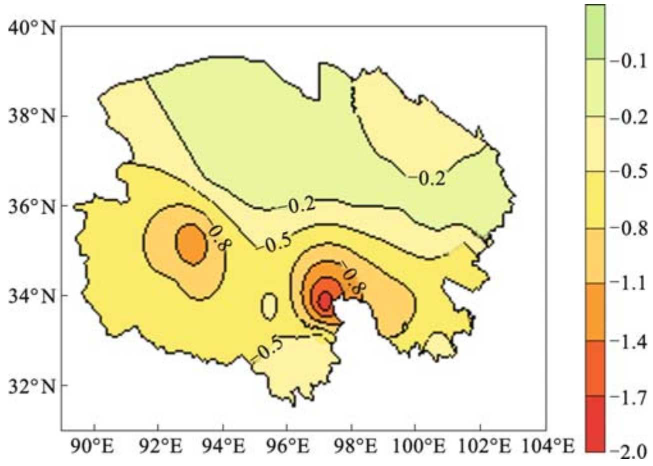

Fig. 7 Moisture index difference pre- and post-doubled CO_2

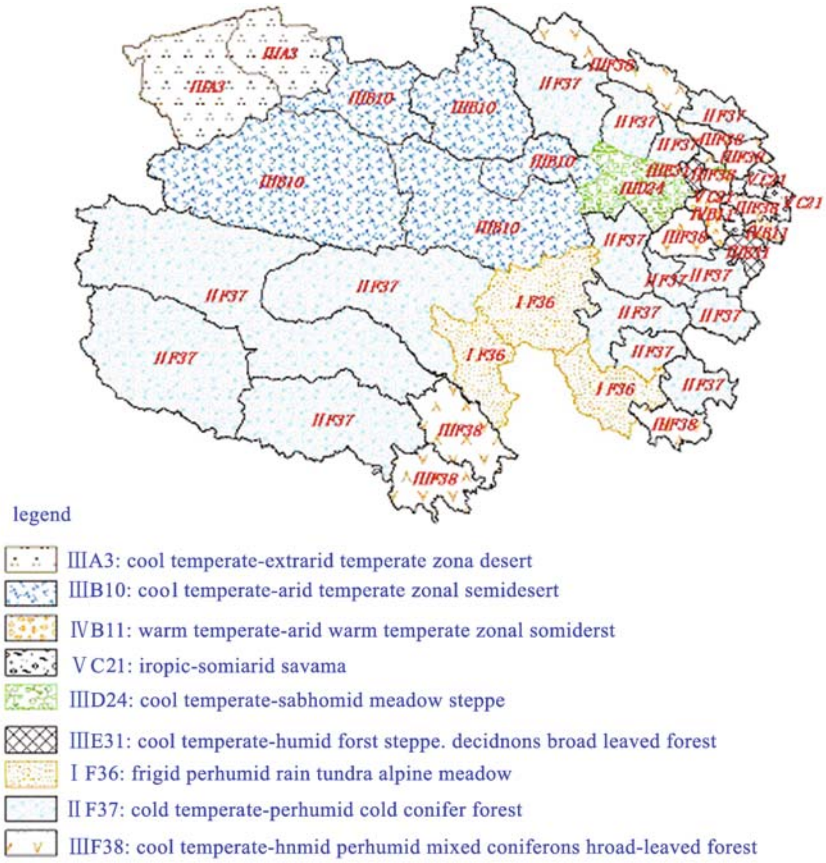

Fig. 8 Grassland type distribution of Qinghai after doubled CO_2

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