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Impact intensities of climatic changes on grassland ecosystems in headwater areas

Yongzhong Feng[1,2], Xiaowei Qin[1,2], Xuemin Ren[1,2] and Gaihe Yang[1,2]*

[1]College of Agronomy, Northwest A and F University, 712100 Yangling, Shaanxi, China.
[2]The Research Center of Recycle Agricultural Engineering and Technology of Shaanxi Province, Yangling, Shaanxi 712100, China.

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Rainfall and temperature are the direct driving factors that affect grassland ecosystem evolution. The study constructed the assessment model of the driving factors, temperature and rainfall, that exerted influence on the primary productivities of the grassland ecosystems in headwater areas, and used the model to quantitatively analyze the primary productivity variations of the grassland ecosystems in the headwater areas with the temperature and rainfall from those in the baseline year on the basis of the nearly forty year climatic data collected by the meteorological stations of Qumalai County, Maduo County, Yushu County and Nangqian County. The results show that over the forty-one years between 1962 and 2002, the rainfall among the climate dominated natural factors was the critical factor that caused the primary productivities of the grassland ecosystems to vary in the headwater areas. Moreover, the temperature was the limiting factor of the primary productivities of the grassland ecosystems in the headwater areas, which gently affect the primary productivities of grassland ecosystems in the headwater areas.

Key words: Climatic change, headwater, grassland, ecosystem, impact intensity.

INTRODUCTION

The degeneration of grassland ecosystem has been well documented in many geographical regions (Kawanabe and Zhu, 1991; Wang, 2004; Nan, 2005). It is widely recognized that temporal and spatial degeneration often occurs due to climatic change (Zhang and Shi, 2000; Mitchell and Csillag, 2001), and many researchers have concentrated on qualitatively studying the response of grassland ecosystems to the changing patterns and the abnormalities of climatic factors (Wang and Shen, 2000; Sitch et al., 2003; Yang et al., 2004). For example, Sun and Mu (2011) suggested that the positive interaction between vegetation and climate (example precipitation and temperature) was an important desertification mechanism within a complex model. However, few studies have determined how strong the impacts of climatic changes on the degeneration of grassland ecosystem and what methods should be adopted to investigate it quantitatively (Zhou et al., 2005; Astapati and Das, 2010).

Sponsored by the Assessment Project of Environmental Evolution and Quality in the Headwater Areas of the Key Science and Technology Frontier Project of Qinghai, this study systematically investigated the baseline grassland data, climatic changes and animal husbandry productions in the headwater areas from April 2002 to August 2006. Depended on the law of energy conservation and the Miami model of climatic net primary production of biomass (Lieth, 1972; Ni, 2004), this study constructed the impact mechanism model of climatic changes on the primary production potentials of grassland ecosystems in the headwater areas, and thus using the model to quantitatively examine how the temperature and rainfall variations affected the grassland ecosystem evolutions in the headwater areas.

Lying at 3450~6621 m above sea level within 89°24′~102°41′E and 31°39′~36°16′N, the headwater areas cover 318000 km^2. As the headwater areas of the Yangtze River, Yellow River and Lantscang River (Feng

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*Corresponding author. E-mail: ygh@nwsuaf.edu.cn. Tel/Fax: +86-29-87092265.

et al., 2004a, b), they are very important ecologically. In the headwater areas, the grassland ecosystems dominate (Li et al., 2006) and hence can be used in featuring their ecosystem evolution orientation. In recent years, increasing human activities and natural environment changes, especially climatic changes, cause the grassland ecosystems to tend to degenerate. Among the factors that affect grassland ecosystem evolution, the dominating natural factors, temperature and rainfall, exert influence on the composition, distributions and functions of vegetation communities. Currently, remote sensing data are used to study the effects of temperature and rainfall-dominated natural factors on grassland ecosystem evolution according to the transformations and variations of grassland ecosystem vegetations at high, moderate and low coverage rates (Akiyama and Kawamura, 2003; Akiyama et al., 2005). By this way, the effects can be generally qualitatively outlined. However, since remote sensing data come from diverse sources, long term sequential variations are difficult to obtain (Chen and Fu, 1996; Jiang et al., 2003; Wang and Cheng, 2001).

In order to provide the scientific methodology and basis for assessing the impact intensities of natural and artificial factors on eco-environmental evolutions in the headwater areas, our study focused on constructing the assessment model of temperature-and rainfall-dominated climatic changes on eco-environment evolutions in the headwaters areas. Thus, depending on the long-term sequential meteorological data of the areas, we used the model to examine the variations of the primary productivities of grassland ecosystems.

MATERIALS AND METHODS

Construction of the impact intensity model of climatic changes on grassland ecosystem evolutions in the headwater areas

Principle and basis followed in the construction of the impact intensity model

Primary production is one of the important indexes that reflect the impacts of climatic changes on the grassland ecosystem. But the primary production of the grassland ecosystem is closely related to the temperature and rainfall (Sun and Mu, 2011). Thus, the study constructed the assessment model of the impact intensity of climatic changes on grassland ecosystem evolution according to the energy conservation law (Zhou et al., 2005; Peng et al., 2010), and took into account the energy conversion efficiencies of the grassland ecosystem (Li et al., 1999) against the temperature and rainfall rather than the other individual energy conversion processes and steps in constructing the assessment model according to the grey box theory as well as its research goals.

According to the investigations about the factors involved in regional eco-environment evolution, the natural factors of the study included the dominating climatic factors (temperature and rainfall) and the dominating topographical factors altitude, slope gradient and aspect. Because altitude and slope gradient and aspect indirectly exert influence on temperature and rainfall and actual calculation in terms of temperature and rainfall actually takes into account the altitude and slope gradient and aspect, the study did not independently carried out the calculation in terms of temperature and rainfall rather than altitude and slope gradient and aspect. In assessing the impact intensities of the temperature and rainfall on grassland ecosystem evolutions in the headwater areas, the study had two assumptions:

(A) Assumption about relevant background values: The study chose relevant background values of the grassland ecosystems in a specific year as its baseline background values of the grassland ecosystems when it carried out the calculation about the impact intensities of the temperature and rainfall on the grassland ecosystem evolutions in the headwater areas.

(B) The primary production of grassland ecosystem is an ideal value and thus difficult to be accurately calculated by a model or an equation. As a result, the study used photo-temperature productivity potential in the place of primary production in its assessment (Ren et al., 1978; Astapati and Das, 2010). According to the law of energy conversion the net productivity or production of an ecosystem is:

$$P_{\mathrm{n}_i} = P_{\mathrm{g}_i} - R_{\mathrm{a}i} \tag{1}$$

Where, P_{ni} stands for the net production in the ith year; P_{gi} stands for the total net primary production in the ith year and R_{ai} stands for the respiration of the ecosystem in the ith year. Herein, the net primary production can be theoretically calculated by Equation (2):

$$P_n = f(T, R) \tag{2}$$

Theoretically, the impact intensities of the temperature and rainfall on the grassland ecosystems in the headwater areas are the partial derivatives of their corresponding terms, calculated by the following equations:

$$P_T = \frac{\partial P_n}{\partial T} = \frac{\partial f(T,R)}{\partial T} \tag{3}$$

$$P_R = \frac{\partial P_n}{\partial R} = \frac{\partial f(T,R)}{\partial R} \tag{4}$$

In the two equations, P_n stands for the net primary productivity of the grassland; P_T stands for the impact intensity of the temperature on the net primary production of the grassland ecosystem, and P_R stands for the impact intensity of the rainfall on the net primary production of the grassland ecosystem. According to Equations 3 and 4, the temperature (T) and rainfall (R) affect the primary production of the ecosystem. Therefore, the net primary production calculation in terms of light, temperature and water are the top priority of the study.

According to assumption (B), the study replaced the primary productions of the ecosystems with their corresponding production potentials. So, the top priority calculation of the study was the calculation of the temperature production potentials and rainfall production potentials of the grassland.

Construction of the assessment model of the impact intensities of natural factors on the eco-environments in the headwater areas

There are many methods to estimate the climatic production potential of lands suitable for animal husbandry (Philipp, 1982; Ni, 2004; Long et al., 2008). This study chose the Miami Model (Lieth, 1972), a model that has been commonly adopted in the world to estimate the temperature and rainfall production potential of natural grassland. The Miami model is as follows:

$$Y_{\mathrm{t}} = \frac{2000}{1 + \exp(1.315 - 0.119t)} \qquad (5)$$

Where, Y_t stands for the temperature production potential of forage grasses (kg·mu^{-1}·year^{-1}); t is the average annual temperature and e is the base of natural logarithm. In order to simplify the calculation of the equation, the study transformed the measurement unit Mu of the equation into hectare and then arrived at:

$$Y_t = \frac{2000 \times 15}{1 + \exp(1.315 - 0.119t)} = \frac{30000}{1 + \exp(1.315 - 0.119t)} \qquad (6)$$

Where the measurement unit of Y_t is kg · ha^{-1}·year^{-1}. And then the equation of the Miami model for estimating the rainfall potential productivity was as follows:

$$Y_{\mathrm{t}} = \frac{2000}{1 - \exp(-0.000664r)} \qquad (7)$$

Where, Y_t is the rainfall potential productivity of forage grasses (kg·mu^{-1}·year^{-1}); r stands for the rainfall (mm) and e is the base of natural logarithm. Equation 5 was also transformed into the following:

$$Y_{\mathrm{t}} = \frac{30000}{1 - \exp(-0.000664r)} \qquad (8)$$

Where the measurement unit of Y_t is kg·ha^{-1}·year^{-1}.

Although this is the most commonly adopted method to estimate the temperature and rainfall production potential, Yang (1994) modified the model as follows according to basic data about alpine cold grasslands of Qinghai-Tibet Plateau when estimating the production potential of the grasslands in the Qinghai-Tibet plateau:

$$Y_t = 856.90[1 + \exp(1.315 - 0.1197\mathrm{t})]^{-1} \qquad (9)$$

$$Y_p = 856.90[1 - \exp(-0.000884p)]^{-1} \qquad (10)$$

Where, Y_t stands for the photo-temperature production potential (kg·mu^{-1}); Y_p stands for photo, temperature and water production potential (kg·mu^{-1}); t stands for average annual temperature (°C), and P stands for average annual precipitation (mm). On converting one mu into one fifteenth of one hectare, the equations were transformed into the following:

$$Y_t = \frac{12853.5}{1 + \exp(1.315 - 0.119t)} \qquad (11)$$

$$Y_p = \frac{12853.5}{1 - \exp(-0.000884p)} \qquad (12)$$

Where the measurement units of Y_t and Y_p are kg ·hm^{-2} (Yang, 1994; Yang et al.,1999).

The model was adopted to estimate the production potentials of the grasslands in the Qiangtang Plateau and the Yijiang Lianghe Region (which is composed of the midstream reaches of Brahmaputra, and the Lhasa River and the Nyang Qu) with the purpose of testing its estimation reliability and accuracy, and was found capable of objectively reflecting the production potential characteristics of the grasslands in arctic alpine regions. Therefore, the study adopted the modified Miami model as its tool to assess the impact intensities of temperature- and rainfall-dominated natural factors on the grassland ecosystem evolutions in the headwater areas.

The temperature production potentials and rainfall production potentials in the headwater areas were estimated by Equations 11 and 12. The variation ratios of the net primary productions with time indicated how strong the dominating natural factors (temperature and rainfall) affect the eco-environment evolutions in the headwater areas. According to assumption (A), the study chose the primary production potentials of the grassland ecosystems in 1961 as the background primary production potentials of the grassland ecosystems and found out the impact intensities of the dominating natural factors temperature and rainfall on the grassland ecosystems by calculating how much the primary production potentials in the other years swung or varied from the background primary production potentials by comparison. In this case, the assessment model of the impact intensities was:

$$p_{t_i} = \frac{Y_{t_i} - Y_{t_{1961}}}{Y_{t_{1961}}} \times 100\% \qquad (13)$$

$$p_{r_i} = \frac{Y_{r_i} - Y_{r_{1961}}}{Y_{r_{1961}}} \times 100\% \qquad (14)$$

Where, P_{ti} and P_{ri} stand for the variations rate of the temperature and rainfall in the ith year from that in the baseline year, that is the impact intensities or amplitude of fluctuation, respectively; Y_{ti} and Y_{ri} stand for the temperature production potential and rainfall production potential in the ith year, respectively; and Y_{t1961} and Y_{r1961} stand for the temperature production potential and rainfall production potential in 1961 as the background temperature production potential and background rainfall production potential, respectively.

Depending on the temperatures and rainfalls in the headwater areas provided by the China Meteorological Administration, the impact intensities of the rainfall and temperature on the production potentials of the grasslands in the typical headwater areas of Maduo County, Yushu County, Qumalai County and Nangqian County was estimated according to Equations 11, 12 and 13 (Table 1).

RESULTS

Impact intensities of climatic changes on the grassland ecosystems in the headwater area of the Yellow River

In the headwater area, rainfall affected the primary productions of the grassland ecosystems differently every year in Yellow river, Yangtze river and Lantscang river regions (Table 1). The net primary productions presented the greatest falls from that in the baseline year (1961) in Maduo County of the Yellow River compared with Yushu County and Qumalai County of the Yangtze River and

Table 1. Impact intensities of the rainfall and temperature on the potentials of the grasslands in the typical regions of the headwater areas (unit: %)

Year	Impact intensity of the rainfall in Maduo county	Impact intensity of the temperature in Maduo county	Impact intensity of the rainfall in Yushu county	Impact intensity of the temperature in Yushu county	Impact intensity of the rainfall in Qumalai county	Impact intensity of the temperature in Qumalai county	Impact intensity of the rainfall in Nangqian county	Impact intensity of the temperature in Nangqian county
1962	174.56	-3.65	11.22	-3.88		11.13	-19.27	0.02
1963	106.68	-3.76	3.88	-7.60		-1.25	-16.49	0.04
1964	58.77	4.73	15.59	3.78	-16.19	10.55	-20.52	0.07
1965	122.35	-14.93	29.48	-4.51	4.76	0.59	-29.58	0.09
1966	65.67	1.42	31.50	4.03	9.05	4.43	-4.08	0.11
1967	46.29	-7.14	7.98	-7.00	-17.25	14.63	-0.89	0.13
1970	129.89	5.17	38.72	4.96	18.51	7.15	-11.86	0.17
1971	96.29	-4.96	3.40	-2.00	11.97	14.10	-16.45	0.20
1972	28.33	-3.76	46.99	-2.94	-10.01	8.81	6.86	0.22
1973	44.95	12.14	-62.79	2.71	6.12	14.35	20.26	0.24
1974	105.60	3.24	27.50	-1.79	38.43	8.78	20.26	0.26
1975	17.56	-2.63	8.06	6.07	-17.35	4.95	-29.90	0.28
1976	-3.09	-7.35	24.16	2.80	-32.30	2.62	-11.16	0.31
1977	55.98	0.60	12.64	0.70	-7.40	5.59	-5.33	0.33
1978	147.14	-13.54	77.17	-4.51	8.81	8.48	5.67	0.35
1979	138.92	-10.41	25.25	-2.17	32.31	8.30	25.10	0.37
1980	130.41	0.45	7.82	3.24	58.22	12.87	-4.56	0.39
1981	10.89	2.89	-12.11	0.31	-40.22	8.54	-32.84	0.42
1982	-11.74	8.28	-15.87	1.66	-41.74	-1.06	-7.46	0.44
1983	-3.14	-2.44	-8.22	0.77	-44.41	14.72	-21.01	0.46
1984	0.71	-10.80	-8.96	-4.67	-48.86	-4.01	-17.65	0.48
1985	10.10	6.72	42.58	8.85	-31.39	2.34	-17.54	0.50
1986	-5.01	-11.97	-10.63	1.27	-40.93	10.13	-26.71	0.52
1987	8.05	-8.35	24.72	1.20	-35.23	16.07	6.50	0.55
1988	4.25	6.90	7.36	3.63	-48.13	11.73	-20.24	0.57
1989	48.37	13.36	11.27	9.86	-42.89	10.19	-18.21	0.59
1990	-29.63	3.01	-18.16	4.47	-49.99	18.00	-25.93	0.61
1991	7.47	-0.28	1.25	1.37	-22.15	6.50	-26.18	0.63
1992	-2.99	11.00	0.12	3.66	-39.55	12.07	-22.85	0.66
1993	-14.55	-2.74	4.36	-0.34	-35.90	17.17	-22.53	0.68
1994	-10.43	3.13	-4.72	2.73	-46.45	15.07	-30.62	0.70
1995	-2.84	8.70	12.73	6.12	-29.02	19.12	4.46	0.72
1996	10.24	2.26	7.94	3.85	-34.65	-0.45	-16.91	0.74
1997	1.92	5.50	13.79	5.93	-32.16	21.83	-18.56	0.77

Table 1. Contd

1998	0.41	-7.30	12.34	-3.08	-25.59	15.66	7.64	0.79
1999	-6.20	14.97	-8.25	10.19	-32.65	12.71	-30.28	0.81
2000	-7.17	15.51	2.84	14.89	-42.23	16.76	-18.14	0.83
2001	6.20	6.96	-2.61	2.61	-29.74	14.75	-31.35	0.85
2002	16.81	10.32	0.20	6.32	-37.93	59.31	-22.48	0.88

Nangqian County of the Lantscang River. During the 19 years from 1962 to 1980, the rainfall caused the primary productions of the grassland ecosystem to fall by more than 100% in nine years, by 50 to 100% in four years, by 0 to 50% in five years and by a percentage below zero in one year. Furthermore, the highest primary production fall amounted to as high as 174.56%. After 1980, the rainfall gently affected the primary productions swinging around the background primary production. Over the forty one years from 1962 to 2002 (Figure 1), the rainfall caused the primary productions in the headwater area of the Yellow River to show a negative increase in eleven years and a positive increase in 30 years in comparison with the primary production in the baseline year. The negative primary production increases mainly appeared after 1980 and the positive primary production increases appeared before 1975. That is to say, over the 19 years from 1962 to 1980 the rainfall presented a positive impact on the grassland ecosystem evolution in Maduo County, and thus they were not the factors that resulted in grassland ecosystem degeneration in the headwater area of the Yellow River. But over the 22 years from 1980 to 2002, there were 10 years when the rainfall presented negative impacts on the grassland ecosystem evolution in Maduo County, which accounted for more than 40% of the years under study, and thus the rainfalls gradually became one of the factors that resulted in the grassland ecosystem degeneration in Maduo County (Figure 1).

In Maduo County, the temperature caused the primary productions of the grassland ecosystem to fluctuate gently, mainly between -20 and 20% (Figure 1). There appeared the peak primary production fluctuation of 15.51% in 1995 and gentle primary production fluctuations around the background primary production in the other years. Thus, the temperature fluctuations caused the primary productions of the grassland ecosystem to see negative and positive impacts in comparison with the background primary production in the baseline year. Over the 41 years from 1962 to 2002, the primary productions saw negative impacts in 23 years of which 15 years distributed among the 21 years from 1981 to 2002, and suffered negative impacts in 18 years of which 11 years distributed among the 19 years from 1962 to 1980 and accounted for more than 55%. The negative and positive impacts of the temperatures occurred in different periods of time. Before 1980, the temperature presented obviously negative impacts on the grassland ecosystem in the headwater area; that is to say, during this period, the temperatures contributed less to the primary production in the headwater area than that in the baseline year and its contribution gradually declined. After 1981, the temperature gradually presented positive impacts on the primary productions in the headwater area as they increased. These are consistent with the temperature fluctuation in the headwater area. Accordingly, the temperature is the main limiting factor in arctic alpine grassland ecosystems if only it is taken into account. Since 1980s, although the temperature has been gradually showing positive impact on the primary production in the headwater area as global warming is on-going, it has still been a limiting factor on the primary production.

In 1962 to 1980, the rainfall variations affected the grassland ecosystems more violently than the temperature fluctuations in the headwater area of the Yellow River (Figure 1). Ren et al. (1978) and Yang et al. (1999) suggested that the impact intensities of climate changes on the grassland ecosystem evolutions depended upon energy flows into the grassland ecosystems. However, the primary productions of the grassland ecosystems limited the amounts of energy that flows into the ecosystems. According to Liebig’s Theory of the Least Factor (Philipp, 1982), the primary productivity of an ecosystem depends on its limiting factors. Thus, in the headwater areas, before 1980 the temperature was no doubt the main limiting factor of the grassland ecosystems. The temperature was taken as the basis for potential productivity estimation. Since 1981, as global warming is ongoing and global drying tends to increase, the two factors temperature and rainfall, the temperature as a single factor have been always presenting a gentle impact on and

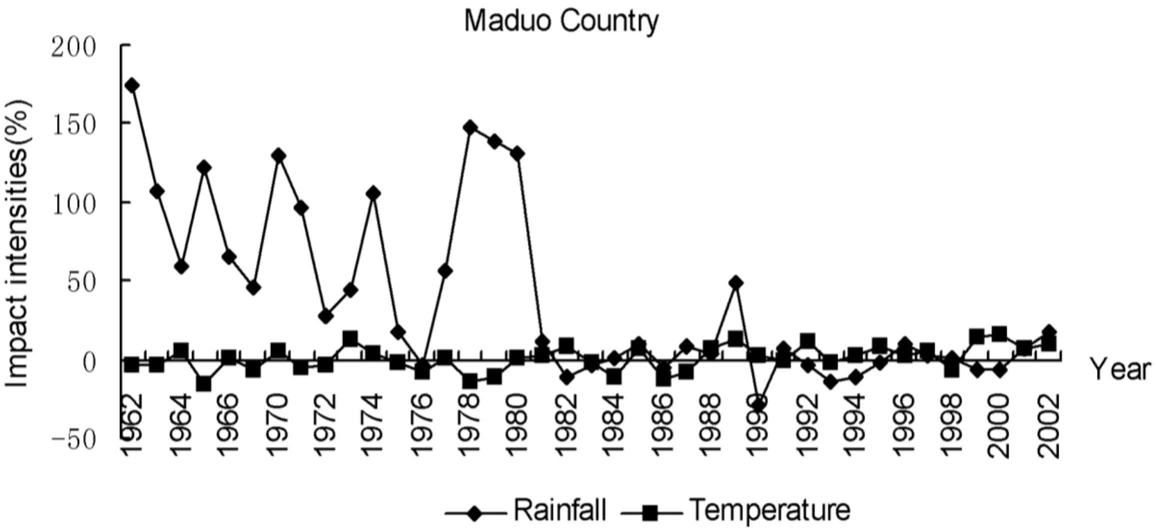

Figure1. Impact intensities of the temperature and rainfall on the grassland ecosystem in Maduo County.

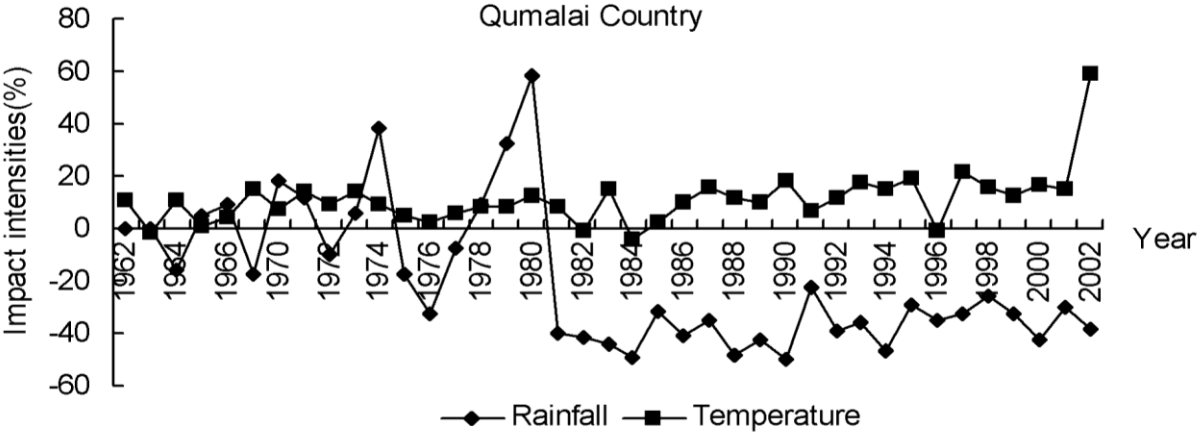

Figure 2. Impact intensities of the temperature and rainfall on the grassland ecosystem in Qumalai County.

making a stable contribution to the eco-environmental evolution in the headwater areas.

Impact intensities of climatic changes on the grassland ecosystems in the headwater area of the Yangtze River

In the headwater area of the Yangtze River, the temperatures affected the grassland ecosystem evolution differently depending on the different altitudes. It always tended to gently affect the grassland ecosystem evolution in low altitude (Yushu County) and remarkably in high-altitude (Qumalai County) and its impacts mainly appeared positive. In Qumalai County, the temperature presented positive impacts in 37 years, tended to intensify its impacts after the year 2000, resulting in its impact intensity in 2002 deviating from that in the normal year by as high as 60.97 (Figure 2). It probably follows that in the Yangtze River, the temperature affected the evolution of alpine cold grassland ecosystems much more than the evolution of similar grassland ecosystems at low altitude regions. The rainfall presented a violent impact. In Yushu County, the rainfall presented negative impacts in 10 years and positive impacts in 31 years and its main impact intensities ranged within -62.79~77.17% (Figure 3). In Quamlai County, the rainfall presented basically the same year to year patterns in its negative and positive impacts on the primary production potential of the grassland ecosystem before 1980, and only negative impacts on the primary production potential of the grassland ecosystem after 1980, that is- the rainfall always declined since 1980.

The above analysis showed that the impact of the temperature on the primary production of arctic alpine ecosystems in the Yangtze River had something to do

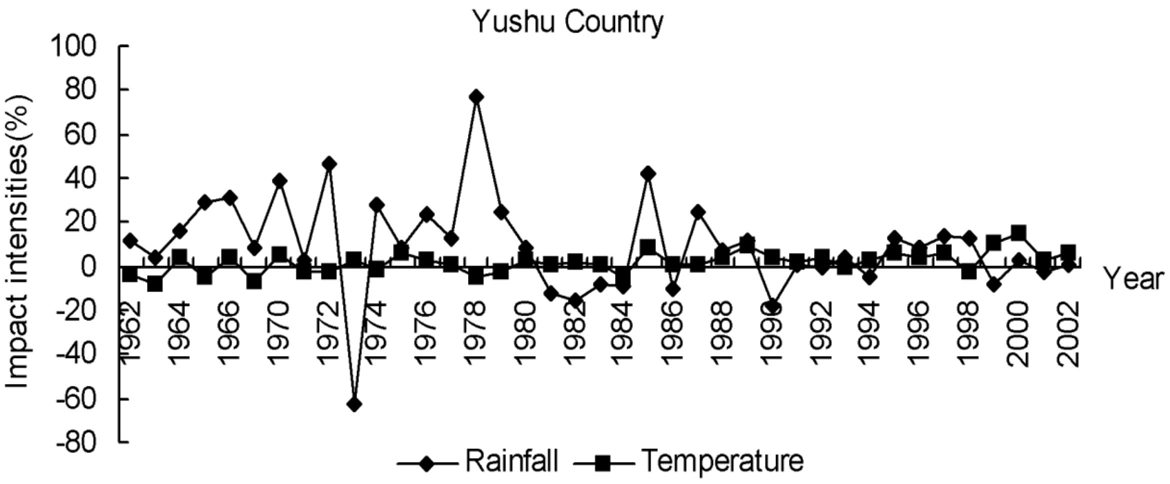

Figure 3. Impact intensities of the temperature and rainfall on the grassland ecosystem in Yushu County.

with the altitude of the ecosystems. In the low-altitude regions, slight global temperature fluctuation still has not caused the potential productivity to decline sharply, while in the regions lying at 4000 m above sea level, the temperature is the limiting factor of the grassland ecosystems and thus its slight fluctuation was capable of causing the primary productivity to fluctuate. In the headwater area, the temperature did not have much impact on the environments in the low altitude regions, but greatly affected the primary productivities of grassland ecosystems in high altitude regions (Figures 2 and 3). After 1980, the impact intensity of the rainfall on the primary productivity of the grassland ecosystem always swung around the background impact intensity in the baseline year in Yushu County and mainly appeared negative in Qumalai County, which matches with the climatic tendency of the headwater area that the rainfall declines and drying gets intensified.

Impact intensities of climatic changes on the grassland ecosystems in the headwater area of the Lantscang River

In Nangqian County located in the headwater area of Lantscang River, the temperature basically did not exert influence on the primary production potential compared with the temperature in the baseline year, although it caused a slight fluctuation after 1988 and later on kept on having a gentle impact (Figure 4). Compared with its impacts in the baseline year (1961), the rainfall fluctuation affected the grassland ecosystem more violently than the temperature fluctuation in the headwater area. Among the forty one years, the rainfall presented positive impacts whose intensities were below 30% in nine years and negative impacts in the other years, that is - in the headwater area, the rainfall was lower in 32 years of the forty one years than that in the baseline year or the background rainfall and as a result it became the limiting factor. And particularly after 1980, this effect became more obvious and drying also appeared remarkable.

DISCUSSION

The degeneration of grassland has long been one of the key research areas in China (Ren et al., 1978; Harazono et al., 1993; Yang, 1994; Wang, 2004). Nan (2005) reported that about 90% of the total usable grassland in China has been degraded to various extents. And Sun and Mu (2011) summarized that the temporal and spatial degeneration of grassland ecosystems often occurs due to climate change and human activity. Moreover, the degeneration also has a great impact on environmental conditions (Gao et al., 2003). Thus, it is important to estimate the potential response of grassland ecosystems to climate changes. Most of the studies involved in these literatures had only dealt with describing such respects as desertification mechanism and the interaction between vegetation and climate (Wang and Cheng, 2001; Zhou et al., 2005). However, quantitative analysis on impact intensities of climate change on grassland evolutions has been rarely found in currently existing literatures concerned (Zhou et al., 2005; Astapati and Das, 2010). Consequently, the impact intensity of climate change on grassland ecosystem evolution has not been easy to understand.

In this study, we constructed the assessment model of the driving factors (temperature and rainfall) that exerted influence on the primary production potentials of grassland ecosystems in the headwater areas, and used the model to quantitatively examine the primary productivity variations of the grassland ecosystems. Herein, only rainfall and temperature involved in constructing the assessment model for action mechanisms on the eco-environments in the headwater areas were used as the

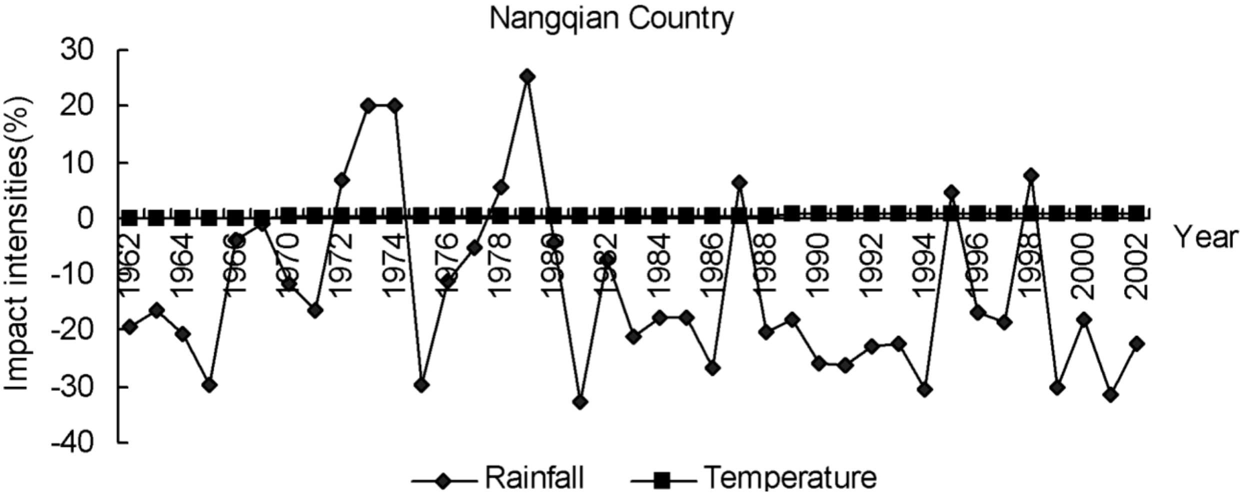

Figure 4. Impact intensities of the temperature and rainfall on the grassland ecosystem in Nangqian County.

main factors and thus the assessment model did not integrated the impacts of natural factors as landform and solar radiation, and artificial factors on the eco-environments that it suffered in its construction accuracy and assessment precision. Therefore, it is necessary to further explore in assessment model construction in the future so as to improve model precision and accuracy.

The method that rainfall potential productivity and temperature potential productivity took the place of the net productivity in assessing the impact intensities of climatic factors on the grassland ecosystems in the headwater areas would have been realistic to some extent if the historical records and remote sensing data had spanned over a short sequence of time. The conclusions of the study were obtained in the reference frame of the baseline year and thus the impact intensities of natural factors on the grassland ecosystem evolutions in the headwater areas were different from their impact intensities in the baseline year (relative ones).

Conclusions

Over the 19 years between 1962 and 1980, the rainfall presented positive impacts on the grassland ecosystem in Maduo County in the headwater area of the Yellow River in relation to its impact in the baseline year (1961), and consequently the rainfall was not the factor that affected the grassland ecosystem degeneration in the headwater area of the Yellow River. Over the 22 years between 1980 and 2002, the rainfall presented decreasing positive impacts in ten years, which accounted for more than 40% of the years under study; that is to say, the rainfall gradually became one of the factors that resulted in the grassland ecosystem degeneration in Maduo County since 1980. Before 1980, the temperature presented obviously negative impacts in the headwater area, that is - the temperature contributed less to the primary production of the grassland ecosystem during this period than in the baseline years and its contributions progressively decreased year by year. After 1981, the temperature gradually presented positive impacts on the primary production of the grassland ecosystem in the headwater area, which matches with its fluctuation in the headwater area. Although the temperature gradually presented positive impacts on the primary production of the grassland ecosystem in the headwater area after 1980s as global warming is underway, the temperature was still a limiting factor that maintained stable impacts during the whole process in relation to the heat necessary for forage grass growth.

In the headwater area of the Yangtze River, the temperature presented positive impacts on the grassland ecosystem in high-altitude Qumalai County in 37 years and this tendency appeared more and more obvious after 2000. The deviation of its impact in 2002 from that in the normal year reached 60.97. The rainfall also exerted violent impacts. In Yushu County, the rainfall presented positive impacts on the grassland ecosystem evolution in ten years and negative impacts on the evolution in 31 years and its impact intensities mainly ranged within -62.79~77.17. In Qumalai County, the number of years when the rainfall presented positive impacts was nearly the same as that of the years when it present negative impacts before 1980 and the rainfall presented negative impacts after 1980, that is - the rainfall kept declining in Qumalai County after 1980.

In the headwater area of the Lantscang River, the temperature potential production kept stable except 1980, when it suffered a slight fluctuation in relation to the background temperature potential production in the baseline year (1961). In the forty one years between 1962 and 2002, the rainfall presented positive impacts whose intensities were below 30% in nine years and negative impacts in the other year that is in the head-water area. Moreover, the rainfall was lower in 32 years of the forty- one years than that in the baseline year or the background rainfall. Therefore, the rainfall became the limiting factor, and particularly after 1980, this effect became more obvious and drying also appeared remarkable.

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