Modelling the effects of climatic factors on the biomass and rodent distribution in a Tibetan grassland region in China

Quanzhen Wang [A], Maolin Xia [B], Bai-Song [B], Xi-Rao-Zhuo-Ma [C], Ba-Sang [D], Jiang-Cuo [E], Zha-Dui [F], Jin-Mei[G], Ze-Duo [G], Surong Li [H], Zha-Xi, Yang-Ba [I], Jia-Yang, Dan-Pei [J], Jian Cui [K] and Jimin Cheng [L]

[A] Department of Grassland Science, College of Animal Science and Technology, Northwest Agriculture and Forestry University, Yangling 712100, Shaanxi Province, People's Republic of China, www.nwsuaf.edu.cn
[B] Grassland Department, Extension Center of Technology for Livestock in Tibet, Lhasa, 850000, Tibet Autonomous Region, P R China,
[C] Grassland Department of Nagqu Prefecture 852000, Tibet Autonomous Region, People's Republic of China
[D] Grassland Department of Ngari Prefecture 859400, Tibet Autonomous Region, People's Republic of China
[E] Grassland Department of Shannan Prefecture 856000, Tibet Autonomous Region, People's Republic of China
[F] Gongbolgyamda County Animal Husbandry and Veterinary Department of Nyingchi Prefecture 860200, Tibet Autonomous Region, People's Republic of China
[G] Qamdo Grazing Headquarter Superviser Secretary of Qamdo Prefecture 854000, Tibet Autonomous Region, People's Republic of China
[H]Jomda County Animal Disease Control Center of Qamdo Prefecture, 854100, Tibet Autonomous Region, People's Republic of China
[I] Grassland Department of Shigatse Prefecture 857001, Tibet Autonomous Region, People's Republic of China
[J] Animal Husbandry Department of Tibetan Pasturage Bureau 850000, Tibet Autonomous Region, People's Republic of China
[K] Department of Biology, College of Life Science, Northwest A&F University, Yangling 712100, Shaanxi Province, People's Republic of China;
[L] State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Institute of Soil and Water Conservation of Chinese Academy of Science & Ministry of Water Resource of China, People's Republic of China.

Contact email: wangquanzhen191@163.com

Abstract: To identify the main climatic factors from 2007 to 2009 that influence biomass and rodent distribution, 576 fixed sample plots within 81 million km^2 of different climatic grassland in Tibet were monitored. The aboveground biomass, the total burrows, the active burrows, the burrow index, and the rodent density in the plots were measured yearly in October. The monthly precipitation and the average temperatures from April to November were obtained for four successive years (2006-2009). Correlative and modelling analyses between the aboveground biomass, the rodent density, and the climatic factors were performed. The results showed that biomass and rodent density were significantly correlated with the climatic factors. Using ridge regression analyses, models of the biomass and rodent density with respect to the monthly precipitations and average temperatures of the previous year were developed. The raw testing data demonstrated that the models can be used approximately to predict biomass and rodent density.

Keywords: Climatic effects, biomass, rodent distribution, model analyses, Tibetan grassland.

Introduction

The Tibetan plateau is the highest plateau in the world and an important part of the global terrestrial ecosystem on the Eurasian continent. As an ecological shelter for the economically developed eastern and central regions in China, grassland has been shown to modify the global climate and to influence the plateau area (Wang *et al*. 2011). Therefore, the protection of grassland from degradation and desertification, which is a process accelerated by rodents, particularly *Ochotona curzoniae*, that have inhabited these areas over the last two decades, is a serious problem (Cang-Jue-Zuo-Ma *et al*. 2010). However, this rodent was determined to respond to the geological and climatic factors in the Tibetan Plateau (Fan *et al*. 2011). Although there have been several ecological studies on the relationship between this rodent and the climatic factors in grassland (Davidson and Lightfoot 2008; Yoshihara *et al*. 2009), studies that focus on the fragile Tibetan grassland ecosystem are limited. In this study, we used data collected over four successive years at a natural Tibetan grassland region to determine the influence of climatic factors on the rodent density and grassland biomass. In addition, we developed models that correlated the measured climatic factors with the rodent density and biomass to predict and monitor the grassland-dwelling rodent distribution and biomass.

Methods

Study site

Our investigations were conducted in the Tibetan Autonomous Region of China. All of the sampling sites were located in six prefectures of Tibet (26°34′ to 32°9′N and 83°10′ to 97°17′E) at an average altitude of 4100 m above sea level and with a mean annual precipitation of 150 to 610 mm.

Data collection

A total of 576 fixed sample plots within 81 million km^2 of different climatic alpine grassland located in six prefectures of Tibet were monitored. The geographic coordinates, including the altitude (denoted X_1), latitude, (X_2) and longitude (X_3), of the plots were recorded in a database. The area of each plot was 667 m^2 (25 m × 26.7 m). The aboveground biomass (Y_5), the total burrows (Y_1), the active burrows (Y_2), and the rodent density (Y_4) in the plots were measured yearly in October. To estimate the relative rodent density, the rodent population was measured as a percentage of the active burrows 24 hours after the burrows in the plots were plugged. The rodents in the plots were trapped to obtain the burrow index (Y_3). The climatic factors, which included the monthly precipitations (X_{12} through X_{19}) and the average temperatures (X_4 through X_{11}) from April to November in four successive years (2006-2009), were obtained from the Meteorological Working Station of the Tibetan Autonomous Region. The combined four-year data consisted of a total of 866 records in the database, in which Y_1 through Y_5 corresponded to the climatic data of the previous year.

Statistics and analysis method

Both the separate and the combined analyses of the four years provided important information. Correlative and modelling analyses of the aboveground biomass, the rodent density, and the climatic factors were performed. The Pearson correlation coefficients between Y_1 through Y_5 and the climatic factors were calculated. The database was split into two sets: the odd-numbered records were composed of the training data (N = 433) and the even-numbered records were used for testing (N = 433). Ridge regression analyses were performed with the training data. The resultant ridge regression models were investigated through linear regression with the testing data. The ridge trace and scatter plots were subsequently plotted. These analyses and plotting procedures were performed using the SAS software (Version 8.2; (SAS-Institute-Inc 1988). The ridge regression and multiple regression analyses were used to avoid the high intercorrelation and multicollinearity between the variables (Chatterjee and Price 1977; Lattin *et al.* 2003). Several procedures have been proposed for the selection of the variable k in ridge regression analysis, but the optimal value of k cannot be determined with certainty (Chatterjee and Price 1977). The training data were transformed in Visio FoxPro using the natural logarithm. This transformation produced better statistical properties and did not ence the essential mathematical relationships between the variables (Lattin *et al.* 2003).

We first defined the following variables: S = ln Y and C_i = ln X_i for i = 1 through 12. The variables (S and C_1 through C_{12}) were then used for the ridge regression analyses (Chatterjee and Price 1977) using the following ridge regression model:

$$S = C\beta + u \qquad (1)$$

where S is an $n \times 1$ vector of the observations of one response variable, C is an $n \times p$ matrix of the observations of p explanatory variables, ß is the $p \times 1$ vector of the regression coefficients, and **u** is an $n \times 1$ vector of the residuals that satisfy $E(\bar{u}) = \dot{C}$ and $E(\mathbf{uu}') = \delta^2 I$. It is assumed that C and S are scaled such that C′C and S′S are matrices of the correlation coefficients. Here, n = 433, and p = 12. Thus,

$$\ln Y = (\sum_{i=1}^{12} \ln Y_i)\beta + u \qquad (2)$$

The logarithmic model (2) above was transformed to yield the following exponential function:

$$Y = e^{\alpha} \cdot \prod_{i=1}^{12} (Y_i \beta) \qquad (3)$$

where α and β are constants.

Equation (3) was used to estimate the Y of all 433 samples. This estimate was denoted $Y_{estimated}$. The actual values (testing data) were denoted Y_{actual}. A general linear regression model was used to compare Y_{actual} with $Y_{estimated}$. An analysis of variance was used to assess the dependent variable Y_{actual} with respect to the parameter estimates of $Y_{estimated}$. The linear regression model is the following:

$$Y_{actual} = \beta + k \cdot Y_{estimated} \qquad (4)$$

Using Equation (4), the model was adjusted to obtain the following model:

$$Y = \beta + k \cdot e^{\alpha} \cdot \prod_{i=1}^{i} (X_i \beta) \qquad (5)$$

In addition, the ridge trace and appropriate scatter plots were graphed. The analyses and graphical procedures specified above were all performed using the SAS software (Version 8.2; SAS Institute Inc 1988).

Results and Discussion

With the exception of Y_1 with X_1 or Y_3, all of the variables were correlated (Table 1). The rodent density (Y_4) was negatively correlated with the monthly average temperatures from April to November (X_4 through X_{11}) of the previous year and with the monthly precipitations from April to November (X_{12} through X_{19}) of the previous year (Table 2). The biomass (Y_5) was correlated with the monthly average temperatures from April to November of the previous year (X_4 through X_{11}), with the exception of the temperatures in April and June, and the monthly precipitations from April to November of the previous year (X_{12} through X_{19}), with the exception of the precipitation in July and August (Table 2). This result was in complete

Table 1. Pearson correlation coefficients of Y_1-Y_5 and the geographic coordinates (X_1-X_3)

	X2	X3	Y1	Y2	Y3	Y4	Y5
X1	0.469***	-0.227***	-0.018	0.275***	0.275***	0.251***	0.190***
X2	1.000	0.165***	-0.080*	0.195***	0.218***	0.169***	0.230***
X3		1.000	-0.365***	-0.340***	-0.172***	-0.402***	0.624***
Y1			1.000	0.599***	0.025	0.660***	-0.543***
Y2				1.000	0.606***	0.962***	-0.408***
Y3					1.000	0.613***	-0.190***
Y4						1.000	-0.494***

F-values are presented along with their statistical differences: * *P* <0.05, ** *P* <0.01, *** *P* <0.0001. N=866

X1-X3, Y1-Y5 present altitude, latitude, longitude, total hole, active hole, hole rate, rodent density and biomass, respectively.

Table 2. Pearson correlation coefficients of Y_1-Y_5 and their last year's monthly average temperatures (X_4-X_{11}) and precipitations of April to November (X_{12}-X_{19})

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Monthly average temperature								
Y1	-0.019	-0.018	0.098**	0.035	-0.003	0.023	-0.128**	-0.151***
Y2	-0.284***	-0.288***	-0.153***	-0.091**	-0.078*	-0.130***	-0.287***	-0.373***
Y3	-0.291***	-0.284***	-0.199***	-0.081*	-0.038	-0.118**	-0.183***	-0.280***
Y4	-0.248***	-0.251***	-0.111***	-0.070*	-0.065	-0.106**	-0.272***	-0.366***
Y5	0.051	0.073*	-0.050	0.114**	0.196***	0.078*	0.264***	0.284***
Monthly precipitaion								
Y1	-0.392***	-0.305***	-0.116**	-0.040	0.141***	-0.296***	-0.292***	-0.305***
Y2	-0.285***	-0.123**	-0.401***	-0.314***	-0.053	-0.277***	-0.233***	-0.212***
Y3	0.001	-0.015	-0.475***	-0.383***	-0.177***	-0.145***	-0.187***	0 0.031
Y4	-0.340***	-0.202**	-0.403***	-0.270***	-0.107	-0.319***	-0.279***	-0.245***
Y5	0.647***	0.667***	0.198***	-0.162***	-0.465***	0.636***	0.410***	0.264***

F-values are presented along with their statistical differences: * *P* <0.05, ** *P* <0.01, *** *P* <0.0001. N=866. Y1-Y5 present total hole, active hole, hole rate, rodent density and biomass, respectively.

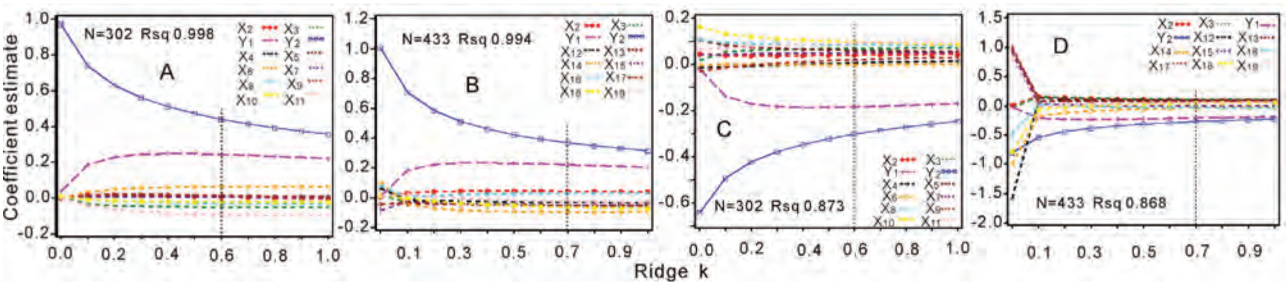

Figure 1. Ridge traces of standard partial regression coefficients for increasing values of k for the climatic factors (X_4-X_{19}) with rodent density (Y_4, A and B) and biomass (Y_5, C and D) and the range regression models, respectively

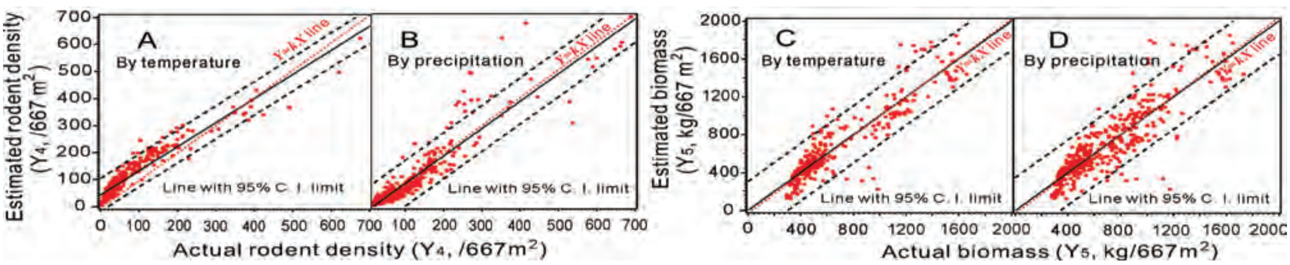

Figure 2. Scatter plot to fit the regression line of actual (testing data) and estimated Y_4 and Y_5, respectively. Y_{est} were estimated by the range models.

agreement with findings reported in the literature (Yarnell *et al.* 2007; Sun *et al.* 2008). The values of Y_4, Y_5, and the climatic factors X_4 through X_{19} significantly differed throughout the four years. It had been previously suggested that the value of k of the ridge regression should be determined from ridge traces in which k is selected from a stable set of regression coefficients (Chatterjee and Price 1977; Lattin *et al.* 2003). Figure 1 shows the standard ridge traces and the models for Y_4 and Y_5. For various values of k (from 0 to 1), the curves of X_4 through X_{19} were stable and asymptotically parallel to the horizontal axis. When the values of k were 0.6 or 0.7, the ridge regression models were obtained using the method developed by Chatterjee and Price (1977). The resultant R2 of ridge regression models are shown in Figure 1. The intersections between the ridge lines indicate that the factors exhibit multicollinearity (Fig. 1) partly due to the differences in the climate between the different years (Yarnell *et al*. 2007). The scatter plots showed that the exponential models were significant at a 95% confidence limit (Fig. 2). These findings suggest that the new models can be used to more accurately predict the values of Y_4 and Y_5 based on the values of Y_1, Y_2, X_2, X_3, and the climatic factors X_4 through X_{19} from the previous year.

Conclusions

The biomass and rodent density were significantly correlated with the climatic factors. Using ridge regression analyses, models of the biomass and rodent density with respect to the monthly precipitations and average temperatures of the previous year were developed. The raw testing data demonstrated that the models can be used approximately to predict the biomass and rodent density.

Acknowledgments

The "Strategic Priority Research Program-Climate Change: Carbon Budget and Related Issues" of the Chinese Academy of Science (Grant No. XDA05050202), funded this work. We are grateful to our skilful Tibetan technical assistants, Da-Wa, Ci-Dan, Ba-Ci, Ci-Ren, De-Qing, Ze-Ren-La-Xi, Bie-Ba-Zhuo-Ga, Zhe-Xi-La-Mu and Ci-Wang-Ba-Dan.

References

Cang-Jue-Zuo-Ma, Li J, Suo-Lang-Ci-Ren, Yang L (2010) Damage and natural enemys of *Ochotona curzoniae* on Tibetan grassland. *Tibetan Science and Technology*, **1**, 56-67.

Chatterjee S, Price B (1977) Regression analysis by example. John Wiley and Sons, Inc., New York.

Davidson AD, Lightfoot DC (2008) Burrowing rodents increase landscape heterogeneity in a desert grassland. *Journal of Arid Environments*, **72**, 1133-1145.

Fan Z, Liu S, Liu Y, Zhang X, Yue B (2011) How Quaternary geologic and climatic events in the southeastern margin of the Tibetan Plateau influence the genetic structure of small mammals: inferences from phylogeography of two rodents, *Neodon irene* and *Apodemus latronum*. *Genetica*, **139**, 339-351.

Lattin JM, Carroll JD, Green PE (2003) Analyzing Multivariate Data. Brooks/Cole, Duxbury Press, Boston, USA. pp. 478-556.

SAS-Institute-Inc (1988) SAS/STAT User's Guide. SAS Institute Inc., North Carolina, USA.

Sun, F, Long, R, Jiang, W, Guo, Z, Nie, X (2008) Alpine meadow plant community biomass and soil bulk density characteristics in different burrowing rodent density plots in the "Three-River Headwaters" region. *Acta Prataculturae Sinica* **17**, 111-116.

Wang Q, Bian Ba Zhuo Ma, Cui J, Hu T, Xu Y, Xie G, Miao Y (2011) Relationship between grassland protection and sustaining household livelihoods in Tibet, China. *African Journal of Agriculture Research* **6**, 1538-1543.

Yarnell, RW, Scott, DM, Chimimba, CT, Metcalfe, DJ (2007) Untangling the roles of fire, grazing and rainfall on small mammal communities in grassland ecosystems. *Oecologia* **154**, 387-402.

Yoshihara Y, Okuro T, Undarmaa J, Sasaki T, Takeuchi K (2009). Are small rodents key promoters of ecosystem restoration in harsh environments? A case study of abandoned croplands on Mongolian grasslands. *Journal of Arid Environments*, **73**, 364-368.