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RESEARCH ARTICLE

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Fluctuation theory and the practice of grassland vegetation in the northern farming-pastoral ecotones of China

Abstract Vegetation fluctuation is an important part of vegetation dynamics. The characteristics of vegetation fluctuation are quite different between grassland and forest communities. By inferring from ecologic and statistical information, grassland vegetation fluctuation and its fluctuation ratio were defined, and an equation for the fluctuation ratio was established for the first time with the fluctuation coefficients specified via expert weighting method. The quantitative grassland vegetation fluctuation and its fluctuation ratio between the years 2002 and 2006 in Yanchi County, Ningxia, northwestern China, in the northern farming-pastoral ecotones, were studied. Results showed that the largest positive fluctuation ratio of 0.685, implying the best vegetation growth in recent years occurred in 2003, while the most negative fluctuation ratio of −1.098, i.e., the worst vegetation growth during this period, occurred in 2005.

Keywords farming-pastoral ecotones of China, grassland vegetation, fluctuation, fluctuation ratio

1 Introduction

Vegetation fluctuation is an important part of vegetation dynamics. Vegetation fluctuation, especially in grasslands, reflects the effects that ecological and non-ecological factors have on vegetation. Current studies of grassland fluctuation are focused on defining vegetation fluctuation (Peng, 1993; Ren et al., 2001), fluctuation types (Haenrich, 1976; Knapp, 1986; Peng, 1993, 1996; Ren et al., 2001), characteristics of fluctuations (Knapp, 1986; Peng, 1993; Peng, 1996), fluctuation mechanism (Coupland et al., 1960; Knapp, 1986; Peng, 1993), fluctuation intensity (Peng, 1993) and other factors. Studies on vegetation ratio, especially in the northern farming-pastoral ecotones of China have not been reported.

Forest community fluctuation and its fluctuation intensity have been studied by Peng (1993) and other scientists, who proposed the concept of vegetation fluctuation intensity. A fluctuation intensity equation was established under the aegis of ecology and statistics by Peng (1993), who played an important role in promoting quantitative plant community studies. Buongiorno and Michie (1980) unified the forest matrix model and the digital planning method, and then proposed methods of measuring the rate of growth from the growth sector, i.e., from the Forest Matrix Model, but it is difficult to apply. Grassland vegetation, especially in the northern farming-pastoral ecotones, is clearly affected by external factors such as climate change and human activity, but is easily observed compared to forest vegetation. Thus, grassland vegetation fluctuation and its fluctuation ratio studies are of practical importance in the following areas: 1) research of grassland vegetation fluctuation as an important part of vegetation dynamics; 2) provision of scientific reference for grassland management; 3) measurement of vegetation ratios in the evaluation of the degree of grassland fluctuation, and as an effective method to forecast future grassland fluctuations.

Based on previous research, and assisted by ecologic theory and statistical information, we have established an equation for the vegetation fluctuation ratio. We carried out our study in the grasslands of Yanchi County, Nigxia Hui Autonomous Region, as an example of grassland vegetation fluctuation in the northern farming-pastoral ecotones, based on the vegetation fluctuation ratio equation. This study is thought to support grassland

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management by providing the means to alleviate the shortcomings in plant dynamics theories.

2 Basic features of vegetation dynamics

Many scientists have defined vegetation fluctuation. Barkman (1958) and Braun-Blanquet (1964) proposed that community dynamics is present only when species differ in certain characteristics (such as coverage, frequency, abundance, biomass, etc.), and they referred to this difference as fluctuation. We are in agreement with Barkman (1958) and Braun-Blanquet (1964), and think that vegetation fluctuation of a plant community deals with annual and seasonal quantitative changes in attribute values affected by short term or periodic climate or moisture changes. Further, the characteristics of vegetation fluctuation are represented by reversibility and relative stability in typical annual or seasonal cycles.

The basic characteristics of vegetation fluctuation are clearly affected by ecological factors, the composition of species and other features. For example, the differences between forest fluctuation and grassland fluctuation are remarkable because the species composition is very different in each community. In general, the basic characteristics of vegetation fluctuation can be divided into four aspects: 1) Fluctuation reversibility. Wherever vegetation occurs, its fluctuation is affected by given factors, and when the factors vanish, the community will revert to its normal state. The normal state is called the "initial state." Generally speaking, it is difficult for vegetation to be restored to its "initial state" after fluctuation occurred (Peng, 1993); 2) Fluctuation direction. Vegetation fluctuation can be divided into positive and negative fluctuation. When positive fluctuation occurs, the community structure will be better than the initial state. On the other hand, with the negative fluctuation, the community structure will be worse off and its ecological functions will decline; 3) The species composition of the community and its basic properties cannot be changed when vegetation fluctuation occurs, i.e., the constituent and dominant species do not change. This is an essential distinction between vegetation fluctuation and succession; 4) In typical situations, the flora is stable and there is no encroachment of new species (Knapp, 1986; Peng, 1996; Ren et al., 2001).

3 Establishment of the grassland vegetation fluctuation ratio equation

Vegetation fluctuates under the effects of internal and external factors. The community structure will either be better or worse off compared to the "initial state". The degree of plant community fluctuation compared with normal years is defined as the fluctuation ratio (FR). The quantitative determination of this vegetation community fluctuation ratio lies at the root of the emphasis in our investigation.

According to Barkman (1958) and Braun-Blanquet (1964), and by our definition of vegetation fluctuation, community dynamics is represented by differences in species characteristics (such as coverage, frequency, abundance, and biomass). Grassland vegetation fluctuation can be measured by using quantitative vegetation attributes, such as coverage, biomass, height, frequency, and so on. We attempted to establish the equation of the grassland vegetation fluctuation ratio for the first time, as follows:

$$FR = \left[c\left(\frac{C_i}{\sum_{i=1}^{r} C_i/r} - 1 \right) + b\left(\frac{B_i}{\sum_{i=1}^{r} B_i/r} - 1 \right) + h\left(\frac{H_i}{\sum_{i=1}^{r} H_i/r} - 1 \right) + d\left(\frac{D_i}{\sum_{i=1}^{r} D_i/r} - 1 \right) \right] \Big/ 4 \quad (1)$$

where FR is the grassland vegetation fluctuation ratio; C_i the grassland vegetation cover in the ith year; B_i the grassland vegetation biomass in the ith year; H_i the height of the grassland vegetation community in the ith year; D_i the grassland vegetation density in the ith year; c, b, h and d are weight coefficients and r is the number of years or months of observation (in our case $r = 5$ years).

We used the Delphi method in order to determine weight coefficients, as shown in Table 1. According to the degree of importance of different vegetation indices (biomass, height, coverage and so on), the vegetation condition is evaluated using four indices measured by expert scoring. If the four indices are all perfect, their score would be four. Because our study area was in the northern farming-pastoral ecotones of China, autologous vegetation characteristics were also considered. The weight evaluation results are presented in Table 1. The weight coefficients of biomass and coverage were large, but height and density indices were small as determined by

Table 1 Expert weight indices for grassland vegetation in the north farming-pastoral ecotones

experts	coverage	biomass	community height	density
expert 1	1.65	1.79	0.23	0.33
expert 2	1.68	1.90	0.20	0.23
expert 3	1.50	1.72	0.28	0.51
expert 4	1.80	1.70	0.26	0.25
expert 5	1.65	1.87	0.28	0.20
expert 6	1.55	1.95	0.23	0.27
expert 7	1.35	1.70	0.43	0.52
expert 8	1.70	1.80	0.28	0.22
expert 9	1.78	1.77	0.18	0.27
expert 10	1.40	1.90	0.33	0.37
mean value	1.61	1.81	0.27	0.32

expert scoring. The experts scored the weight coefficient *c* as 1.61, *b* as 1.81, *h* as 0.27 and *d* as 0.32 (Table 1). Replacing the coefficients *c*, *b*, *h* and *d* in equation (1) with their respective weights, the grassland vegetation fluctuation equation in the northern farming-pastoral ecotones was established as follows:

$$FR = \left[1.61 \times \left(\frac{C_i}{\sum_{i=1}^{r} C_i/r} - 1 \right) + 1.81 \times \left(\frac{B_i}{\sum_{i=1}^{r} B_i/r} - 1 \right) + 0.27 \times \left(\frac{H_i}{\sum_{i=1}^{r} H_i/r} - 1 \right) + 0.32 \times \left(\frac{D_i}{\sum_{i=1}^{r} D_i/r} - 1 \right) \right] \Big/ 4 \quad (2)$$

In general, coverage is one of the most important indices of vegetation growth. However, usually, a certain amount of subjectivity is inevitable in such a survey of vegetation coverage, and the field survey results for coverage were not uniform among the experts. In contrast, biomass was measured using a weight balance, thus the investigation results were more standardized. For this reason, the weight coefficient of biomass *b* was larger than that of coverage weight coefficient *c* (the other two quantitative vegetation characteristics, community density and height, are less reflective of vegetation growth conditions).

4 Studies of grassland vegetation fluctuation ratio in the north farming-pastoral ecotones: the example of Yanchi County, Ningxia Hui Autonomous Region, China

4.1 Survey of the study area

Yanchi County (37°04′–38°10′N, 106°30′–107°41′E), with an area of 6700 km^2, is located in the eastern part of the Ningxia Hui Autonomous Region. The landform is a denudate pane plain in the south and low in the north with an elevation between 1295 and 1951 m. The physiognomy falls clearly into two landform units: loess covered hills in the south and gentle Ordos hills in the north. The area has a typical continental climate in an intermediate temperate zone, with an annual temperature of 8.1°C. The annual growth period is 165 d, and annual precipitation is around 250–350 mm. Precipitation decreases from the south to the north, and from the southeast to the northwest. Most of the agrotypes are sierozem, calcic kastanozems soil and aeolian sandy soils, with smaller areas of solonchak and planosol soils. Vegetation types include shrubs, grassland, meadows and semi-desert vegetation, of which shrubs, grassland and semi-desert vegetation, by far, account for the greatest percentage and have large distributions. The grassland is categorized as arid grassland and desert steppe, and plants in the communities are xeromorphic and middle xeromorphic.

4.2 Data acquisition

With support from the National Scientific Research Foundation (30771764) and the National Desertification Position Monitoring Project, field investigations were carried out in the growing season from June to August (2002–2006). The items investigated were plant names, number of plants (of each species), coverage, height, biomass, etc. Most of the plant species under consideration were annual herbs. The plots were 1 m × 1 m quadrates.

4.3 Quantitative grassland vegetation fluctuation in the northern farming-pastoral ecotone in Yanchi County

The fluctuation of quantitative vegetation values in the study area is listed in Table 2. This table shows that coverage, biomass, density, community height and the number of plant species in the study area fluctuated widely during 2002–2006. It fully suggests that the environment in the farming-pastoral transitional zone is fragile and labile.

Table 2 Fluctuation of vegetation characteristic number in Yanchi County, Ningxia (2002–2006)

year	coverage/ %	density/ 10^4 plants·hm^{-2}	species number	biomass/ kg·hm^{-2}	height/ cm
2002	66.98	278.14	57	3792.54	9.747
2003	69.70	209.27	46	3854.41	10.963
2004	60.23	152.57	51	4197.41	17.360
2005	36.02	75.68	43	2617.89	15.273
2006	48.40	216.98	65	2030.25	12.090
mean	56.27	186.53	52.4	3298.50	13.087

Table 2 shows that vegetation coverage in the study area fluctuated between 2002 and 2006, with yearly measurements of 66.98%, 69.7%, 60.23%, 36.02%, and 48.4% respectively. The mean coverage was 56.27%. The vegetation coverage in 2002, 2003 and 2004 were thus higher than the annual average, while that in 2005 and 2006 was lower. The highest vegetation coverage in recent years was therefore 69.7% in 2003, and the lowest was 36.02%, in 2005.

In grassland vegetations, community biomass reflects vegetation growth conditions to a much greater extent than coverage, density, height etc. The reason is that biomass is mainly composed of edificato (the species in the northern farming-pastoral ecotone were mainly perennial herbs and semi shrubs) and the dominant species in the community. During years of normal precipitation, the edificato and dominant species grew well and occupied a large amount of space, narrowing the niches of herbaceous companion species to the extent that some of them disappeared in dry years. Community biomass in the study area was 3792.54, 3854.41, 4197.41, 2617.89 and 2030.25 kg/hm^2 respectively from 2002 to 2006, with a mean of 3298.5 kg/hm^2. The biomass in 2002, 2003 and 2004 was thus higher than the mean annual value, but lower in 2005 and 2006.

Usual findings during field investigations show that community density seems clearly affected by precipitation from previous years. Since abundant antecedent precipitation might lead to rapid growth of therophytes thus leading to a higher community density, the measured community density could not have been measured accurately, and the weight coefficient provided by the experts could have been less than that of other vegetation indices. Large numbers of therophytes grew in the study area as a result of abundant precipitation in 2002 and 2006. This led to higher community densities in the two years, i.e., 278.14×10^4 and 216.98×10^4 plants/hm^2 respectively, with both being higher than the mean annual density of 186.53×10^4 plants/hm^2. The density in 2003 was 209.27×10^4 plants/hm^2, also higher than the mean value. The lower densities found in 2004 and 2005 were 152.57×10^4 and 75.68×10^4 plants/hm^2 respectively.

The community height during the years 2002–2006 was 9.78, 10.96, 17.36, 15.273 and 12.09 cm respectively, with a mean of 13.09 cm. This average community height can reflect the vegetation growth pattern to a certain extent. The weight coefficient of the community height, estimated by the experts at 0.27, was less than that for coverage and biomass.

4.4 Grassland vegetation fluctuation ratio in northern farming-pastoral ecotone

Based on our equation for grassland vegetation fluctuation ratio (2) and the quantitative vegetation fluctuation we investigated in the field (Table 2), annual grassland vegetation fluctuation ratios in the study area were calculated (Table 3). Results show that the vegetation fluctuation ratios during the years 2002–2006 were 0.666, 0.685, 0.637, −1.098 and −0.889 respectively in study area. The fluctuation ratio implies a deviation from normal years in terms of vegetation growth patterns, presenting as either extensive or intensive fluctuation. Zero was chosen as the norm from which to base positive or negative grassland vegetation fluctuation ratios. A positive fluctuation ratio means better vegetation growth and a negative value means a decrease in vegetation growth. The largest positive fluctuation ratio calculated was 0.685, in 2003. The ratios in 2002 and 2004 were in second and third place, with values of 0.666 and 0.637 respectively. The most negative fluctuation ratio was −1.098, seen in 2005. The second lowest value, −0.889, was in 2006. Generally, a vegetation fluctuation ratio above zero indicates better vegetation growth than in a normal year, and the larger the vegetation fluctuation ratio, the better the vegetation growth. In contrast, a vegetation fluctuation ratio below zero indicates a decline in vegetation growth from a normal year. The larger absolute negative vegetation fluctuation ratio of the years 2005 and 2006 displayed much worse vegetation growth. Figure 1 shows the curve of vegetation fluctuation ratios from our northern farming-pastoral ecotones, drawn from the values of Table 3. The change of the grassland vegetation fluctuation ratio is shown visually in the curve.

Table 3 Vegetation fluctuation ratios in northern farming-pastoral ecotones (2002–2006)

year	2002	2003	2004	2005	2006
FR	0.666	0.685	0.637	−1.098	−0.889

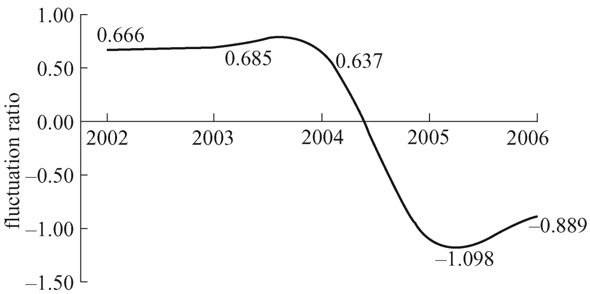

Fig. 1 Curve of vegetation fluctuation ratio in study area

According to our quantitative investigation of characteristic grassland vegetation fluctuation and its attendant fluctuation ratio in the study area, the largest positive fluctuation ratio appeared in 2003, which was the best year for vegetation growth in recent years. The most negative fluctuation ratio, −1.098, appeared in 2005, the worst year for vegetation growth recently.

5 Discussion

Using knowledge of ecology and statistical information combined with measurements of the fragile and peripheral characteristics of vegetation in the area, a fluctuation ratio equation for grassland vegetation in the northern farming-pastoral ecotones was established. This equation is a quantitative method for a quick measurement of grassland vegetation fluctuation. The vegetation fluctuation ratio coefficients were obtained using an expert scoring method. Usually, an expert weight scoring method can be used, however, to a certain extent, some flaws were found due to subjective intrusion. Different perceptions of experts on this problem led to different weighting values. An improvement in the grassland vegetation fluctuation ratio equation and the method of defining the weighting coefficients should be required in further research.

The fluctuation between grassland communities, especially in the northern farming-pastoral ecotones and forest communities has similarities and differences in many respects. The similarities appeared in three aspects: first, grassland or forest vegetation fluctuation does not change the community properties directly; second, fluctuation is a reversible process, which is different from other dynamic forms such as regeneration and succession (Zhou, 2000). This fluctuation is affected by annual climate changes (seasonally, monthly) and quantitative instead of qualitative changes in the community. Because of the unique geographical location and fragile environment, grassland vegetation fluctuation, especially in these northern farming-pastoral ecotones, has obvious characteristics which follow the annual climate cycle and are easy to observe. In contrast, the climate does not have much of a direct effect on forest vegetation, which leads to great difficulty in studying forest vegetation fluctuation. For this reason, researchers are much more interested in forest community succession than in fluctuation.

At present, systematic studies of vegetation fluctuation of grassland communities in the farming-pastoral ecotone in northern China are conducted less frequently than those of the forestry communities in southern China. Spatial rather than temporal research methods are largely adopted (Zhu, 1987; Peng, 1994; Yu et al., 2002; Wang et al., 2003). However, long-term research methods for observation and recording are less used due to shortages in funds, manpower, etc (An et al., 1997; Zhang et al., 2004). There are many insurmountable problems concerned with spatial rather than temporal methods, such as the accuracy of divided, successional stages. Therefore, long-term observations are the more indispensable methods in vegetation fluctuation studies. More funds ought to be allocated to establishing future ecological stations, and more ecological stations should be established for the study of vegetation fluctuation, especially in the farming-pastoral ecotones of northern China.

6 Conclusions

1) Based on ecology and statistical information, we have established the grassland vegetation fluctuation ratio equation (1).

2) Combined with a few vegetation characteristics in the northern farming-pastoral ecotones, of which the weight coefficients c, b, h and d were 1.61, 1.81, 0.27 and 0.32 respectively, vegetation fluctuation ratio coefficients were obtained on the basis of an expert weight scoring method. These coefficients were matched with the fluctuation ratio equation to quantify the grassland vegetation in the area.

3) The quantitative grassland vegetation characteristics clearly fluctuated in the study area during recent years. Taking coverage and biomass as examples, coverage during the years from 2002–2006 was 66.98%, 69.7%, 60.23%, 36.02% and 48.4% respectively. The annual mean coverage was 56.27%. The biomass from 2002 to 2006 was 3792.54, 3854.41, 4197.41, 2617.89 and 2030.25 kg/hm^2 respectively, with an average value of 3298.5 kg/hm^2.

4) Using the fluctuation ratio equation that we established for the grassland vegetation in the northern farming-pastoral ecotones, the vegetation fluctuation was calculated. The vegetation fluctuation ratios in the study area were 0.666, 0.685, 0.637, −1.098 and −0.889 in the years 2002–2006. The largest positive fluctuation ratio was 0.685, in 2003, and implies better vegetation growth.

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