Chapter 4
Long-Term Study of the Relationship Between Precipitation and Productivity in the Main Pasture Vegetation of a Steppe Ecosystem in Eastern Mongolia

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Keywords Aboveground phytomass • Eastern Mongolia • Plant community • Steppe

4.1 Introduction

Large-scale global changes in the natural environment have become more apparent in recent years. These changes are tracked on different levels in all geospheres of the earth and are having an increasing influence on human society. One indication of global change is increased air temperature, which began approximately 100 years ago (Kasimov and Klige 2006). The consequences of this warming, which have become apparent during the past few decades, include soil erosion, decreased vegetation cover, and alterations in the functioning of arid and semiarid ecosystems of which primary production is determined by annual temperature and precipitation. Understanding the consequences of climate change to plants and ecosystems is important for Mongolia because its economic condition depends on livestock production. We have been studying the dynamics of aboveground phytomass in three dominant vegetation communities in Tumentsogt since 1982. The objective of this study was to reveal how the dynamics of aboveground phytomass relate to changes in climatic factors.

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4.2 Study Site and Materials

4.2.1 Location

The eastern steppe permanent study site of the Joint Russian–Mongolian Complex Biological Expedition is located in the territory of Tumentsogt sum of Suhbaatar aimag between 47°15′ and 47°38′ N and 112°02′ and 112°43′ E.

In 1960, Tumentsogt sum was created as an administrative unit, simultaneously with a state farm of the same name. The main economic activity has been animal husbandry, but since 1966 pasture stock-breeding has also been conducted. Before 1998 the general area of agricultural fodder comprised 212,350 ga, of which 193,198 ga was used as pasture, 9,724 ga was hayfields, and 9,428 ga was ploughed fields.

4.2.2 Landscape

The territory of Tumentsogt sum lies in Dundad-Halha county of the eastern Mongolian flat area (Tsegmid 1968). Based on a geomorphological map (Timofeev 1984), the dominant landform types include high (1,100–1,260 m), medium (1,050–1,150 m), and low (900–1,080 m) plains, as well as mountains of two morphogenetic groups: (1) more recently formed low mountains and plateaus, located primarily in the west and to some degree east of the center of the sum, and (2) older formations, including denudational and lithomorphic mountains, which are widespread in the south and east of the sum.

4.2.3 Climate

The most important factors affecting the eastern Mongolian steppe ecosystem are the specific temperature and moisture conditions during the vegetative growth period. These factors are more important than the dry conditions during the winter period. This region is subjected to a harsh continental climate, which reduces the period of vegetative growth.

Precipitation falls mainly in summer, renewing the soil moisture supply. Based on its climate type, the territory of Tumentsogt sum is a part of the comparatively moist Kherlen area (Badarch 1971).

The average annual air temperature is +1.5°C. The length of the frost-free period is 198 days, annual average wind velocity is 3.9 m/s, and annual precipitation is 249.7 mm (Fig. 4.1). The majority of the precipitation is associated with the summer monsoon (May–September), when an average of 239.2 mm falls (95.8% of annual total).

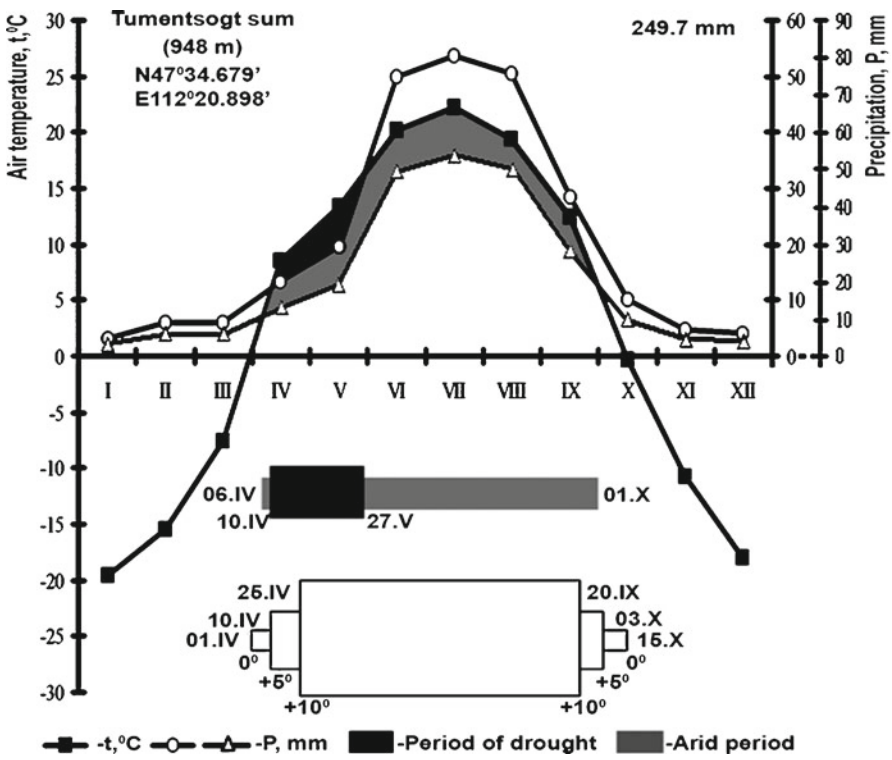

Fig. 4.1 Climate diagram of the meteorological stations at Tumentsogt sum

During this long-term study, 38.5% of years had drought, 34.6% were normal, and 26.9% were humid. The long-term trends in precipitation and average air temperatures are shown in Fig. 4.2.

Trends in mean annual precipitation and air temperature (Fig. 4.2) during the research years show that mean annual precipitation decreased by 34 mm and mean annual air temperature increased by +1.3°C, indicating climate change in the eastern steppe of Mongolia.

We conducted long-term observations on the dynamics of aboveground biomass in three plant communities representative of the eastern Mongolian steppe.

1. *Filifolium sibiricum* community. The study site representing the *F. sibiricum* community (*F. sibiricum* + *Bupleurum scorzonerifolium* + *Ptilotrichum dahuricum* + *Cymbaria dahurica* + *Stipa grandis* + *S. sibirica*) was located on the flat top of a small ridge formed on eluvial-diluvial granite and sandstone at a height of 1,100 m, 12 km northwest of the central Tumentsogt sum homestead. In an area of 60 × 50 m, 107 species of vascular plants belonging to 29 families and 69 genera were recorded. The most representative families were Leguminosae

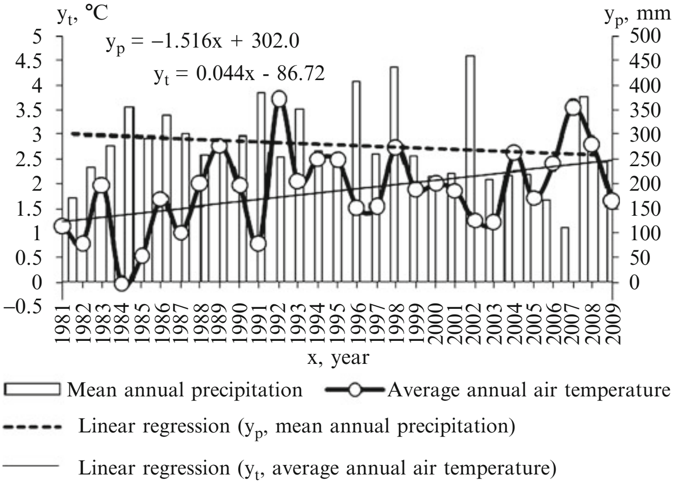

Fig. 4.2 Trend in mean annual precipitation (mm) and mean annual air temperature (°C) at Tumentsogt meteorological station

(16 genera), Compositae (15 genera), and Gramineae (11 genera). Of the vascular plant species, 82.9% were perennials, 13.5% were annual-biennials, and 3.6% were shrubs and semi-shrubs.

2. *Elymus chinensis* community. The *E. chinensis* community (*E. chinensis* + *Poa attenuata* + *Potentilla bifurca* + *Iris dichotoma* + *Saposhnikovia divaricata* + *Stipa krylovii*) was located in the higher part of a valley at a height of 1,070 m, 15 km west of sum center. In a 60×50 m area, 79 species of vascular plants, belonging to 22 families and 53 genera, were recorded. The most dominant families were Compositae (14 genera), Leguminosae (11 genera), and Gramineae (8 genera). Of the vascular plant species, 78.1% were perennials, 17.1% were annual-biennials, and 4.8% were shrubs and semi-shrubs. Canopy cover varied from 40% to 65%. An indicator of this community is the Chinese-Manchurian–Daurian-Mongolian species *E. chinensis* (Lavrenko 1978). It is one of the most widespread species throughout Mongolia and is very abundant in the eastern part of the country (Yunatov 1950; Dashnyam 1974).
3. *Stipa grandis* community. The *S. grandis* community (*S. grandis* + *S. sibirica* + *Serratula centauroides* + *Potentilla tanacetifolia* + *Polygonum divaricatum* + *Caragana microphylla*) was located in the center of a plain between hills, at an elevation of 925 m above sea level. A 100×100 m area was enclosed in 1982 to study the influence of pasture livestock on the steppe ecosystem. Plants belonging to 26 families and 59 genera were recorded in this enclosed area. The most representative families were Compositae (12 genera), Gramineae (12 genera),

Rosaceae (9 genera), and Leguminosae (9 genera). There were 17 species of annuals and 14 species of biennials. Canopy cover was 45–65%. Edificators of the community are *S. grandis* and *S. sibirica*.

4.3 Methods

Aboveground biomass dynamics studies were conducted in the *F. sibiricum* and *E. chinensis* communities from 1982 to 1997, and from 1982 to 2009 in the *S. grandis* plot. Phytomass calculations were conducted for 1-m^2 plots during the spring–summer–autumn period (May–September) on the 10th day of every month. The vegetation was cut at ground level and separated by species.

The total plant canopy cover was determined, and the average height and phenological condition of each species was noted. Cut grasses were air-dried and weighed separately by species.

Meteorological data for 1982–2009 from the weather station in Tumentsogt were used. Data were processed by means of standard statistical methods.

4.4 Results and Discussion

4.4.1 Productivity Dynamics of Aboveground Green Phytomass

The general performance of perennials in the *Filifolium* community in terms of aboveground phytomass is shown in Fig. 4.3.

The maximum aboveground living phytomass in the *F. sibiricum* community ranged from 11.8 (1986) to 23.5 centner/ha (1985), and averaged 15.9 centner/ha. The general trend in perennial green phytomass was described by a polynomial equation ($R^2=0.98$).

The general performance of perennials in the *Elymus* community in terms of aboveground phytomass is shown in Fig. 4.4.

The maximum aboveground living phytomass in the *E. chinensis* community ranged from 8.3 (1986) to 28.4 centner/ha (1985) and averaged 14.7 centner/ha. The general trend in perennial green phytomass was expressed as a polynomial equation ($R^2=0.994$).

The general performance of perennials in the *Stipa* community in terms of aboveground phytomass is shown in Fig. 4.5.

The maximum aboveground living phytomass in the *S. grandis* community ranged from 4.7 (2007) to 21.2 centner/ha (1985) and averaged 13.0 centner/ha. The general trend in perennial green phytomass was expressed as a polynomial equation ($R^2=0.90$).

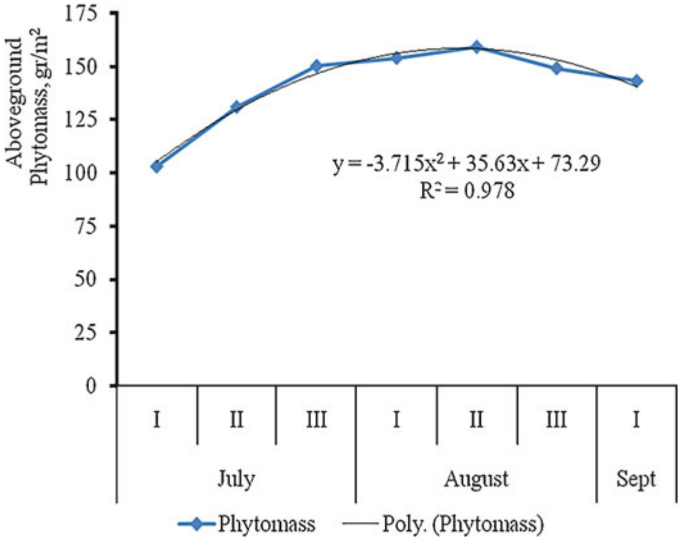

Fig. 4.3 Average 10-day accumulation of green phytomass in the *Filifolium sibiricum* community for the period of vegetation growth during the study period (1982–1997)

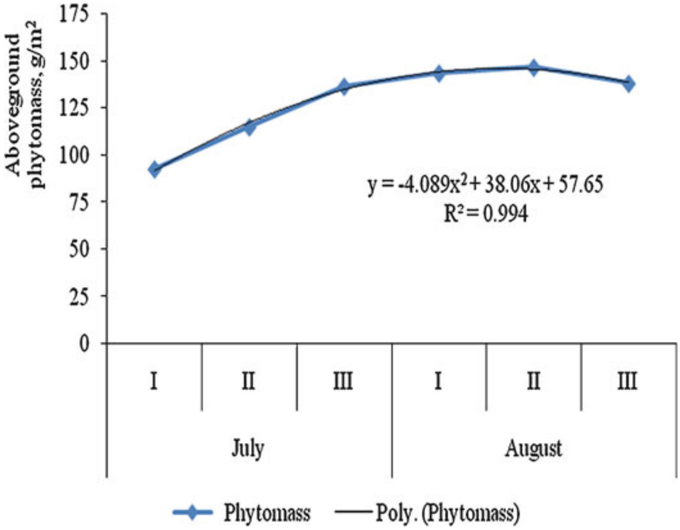

Fig. 4.4 Average 10-day accumulation of green phytomass in the *Elymus chinensis* community for the period of vegetative growth during the study period (1982–1997)

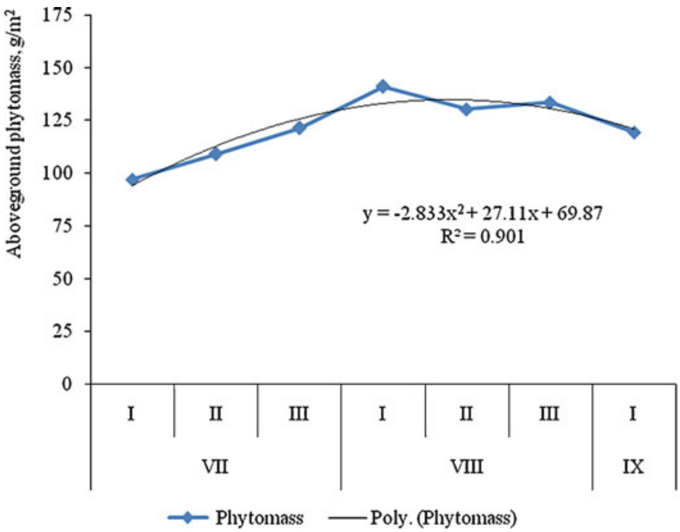

Fig. 4.5 Average 10-day accumulation of green phytomass in the *Stipa grandis* community for the period of vegetative growth during the study period (1982–2007)

4.4.2 Dependency of Green Phytomass Dynamics on Weather Conditions

The main factors defining plant communities and the formation of green phytomass in the dry steppes of eastern Mongolia were rainfall and the pattern of increasing temperature in the spring. Table 4.1 shows that a correlation exists between years of maximum phytomass and spring precipitation and temperature. Maximum phytomass depended on precipitation in April, May, and June ($r=0.56$, 0.82, 0.65), but differed among communities, which was caused by differences in relief, soil conditions, and, most significantly, plant community structure. The negative correlation with temperature ($r=-0.63$, –0.55, –0.50) can be explained by the association between lower temperatures and precipitation. That is to say, during hot years, dry springtime maximum phytomass was low, but during wet years with low springtime temperatures, phytomass was greater. There was a negative relationship between the amount of spring (IV + V + VI) precipitation and the time required to reach maximum phytomass in all three communities ($r=-0.64$, –0.75, and –0.63, for the *Filiformis*, *Elymus*, and *Stipa* communities, respectively). Thus, in years with moist springs, maximum green biomass was reached more quickly than in years with drier springs.

Precipitation and temperature did not produce immediate effects on phytomass; rather, time was required for these abiotic factors to influence the vegetation. Table 4.2 shows the correlation between the weather and biomass at 10-day intervals. Phytomass depended significantly on the rainfall ($r=0.98$, 0.92, 0.93) of previous

Table 4.1 Correlation matrix between spring weather factors and maximum amount of green phytomass and the period required to attain maximum phytomass

Factor	Sampling interval (month)	Maximum phytomass			Period of maximum phytomass		
		1	2	3	1	2	3
Precipitation	IV	0.45	0.66	0.43	–0.38	–0.11	–0.22
	V	0.27	0.46	0.22	–0.33	–0.52	–0.40
	VI	0.43	0.72	0.74	0.01	–0.68	–0.33
	IV + V	0.39	0.63	0.07	–0.49	–0.51	–0.44
	IV + V + VI	0.56	0.82	0.65	–0.64	–0.75	–0.63
	V + VI	0.46	0.76	0.57	–0.09	–0.56	–0.41
Temperature	IV	–0.16	–0.02	–0.43	–0.12	–0.08	–0.02
	V	–0.13	–0.06	–0.33	–0.05	–0.53	–0.38
	VI	–0.51	–0.59	–0.30	–0.12	–0.30	–0.18
	IV + V	–0.32	–0.04	–0.32	–0.18	–0.56	–0.35
	IV + V + VI	–0.63	–0.55	–0.50	–0.23	–0.01	–0.35

1, *Filifolium sibiricum* community; 2, *Elymus chinensis* community; 3, *Stipa grandis* community

Table 4.2 Correlation matrix for 10 days of weather factors and phytomass amount

Factor		Phytomass		
		1	2	3
Precipitation	P_i	0.05	0.15	0.01
	P_{i-1}	0.38	0,41	0,57
	P_{i-2}	0.83	0.85	0.88
	P_{i-3}	0.98	0.92	0.93
Temperature	T_i	0.58	0.59	0.61
	T_{i-1}	0.65	0.80	0.78
	T_{i-2}	0.77	0.81	0.76
	T_{i-3}	0.67	0.77	0.74

i, 10-day period (commencing on 30 April); 1, *Filifolium sibiricum* community; 2, *Elymus chinensis* community; 3, *Stipa grandis* community.

periods (particularly 20–30 days prior), and on the temperature ($r = 0.77, 0.81, 0.76$) of the preceding 10 days (10–20 days). Table 4.3 shows the various meteorological factors that directly influenced green phytomass. This relationship was described by the following multivariate regression equations.

For the *F. sibiricum* community:

$$Y = 0.9638 + 0.3313X_3 + 0.0594X_2 - 0.0179X_1$$

The multivariate correlation coefficient was $R = 0.956$, and the determination coefficient was $D = 0.92$. The shares of the influence variables, obtained using the calculation method of Liepa (1973), were as follows: $X_1 = 36.4\%$, $X_2 = 18.2\%$, $X_3 = 37.3\%$.

Table 4.3 Correlation coefficients between integrated (total) meteorological factors and amount of green phytomass

Community	Factor	X_1	X_2	X_3
Filifolium sibiricum	Y	0.949	0.958	0.948
Elymus chinensis	Y	0.932	0.934	0.936
Stipa grandis	Y	0.870	0.904	0.878

Y, phytomass; X_1, temporal factor (before cropping), commencing on 1 May; X_2, volume of rainfall before cropping (sample collection), since 1 May; X_3, mean day temperature since 1 May

For the *E. chinensis* community:

$$Y = 8.5698 - 0.49497X_3 + 0.025X_2 + 0.0301X_1$$

Here, the multivariate correlation coefficient was $R=0.89$, the determination coefficient was $D=0.79$, and the shares of the influence variables were $X_1=30.2\%$, $X_2=13.4\%$, $X_3=35.7\%$. These influencing factors had a combined influence of 79.3%. The average percentage error in the calculations was 0.13.

For the *S. grandis* community:

$$Y = 17.83 - 0.928X_3 + 0.071X_2 - 0.0444X_1$$

In this community, the multivariate correlation coefficient was $R=0.93$, the determination coefficient was $D=0.87$, and the shares of the influence variables were $X_1=41.0\%$, $X_2=8.7\%$, $X_3=37.8\%$. These influencing factors had a combined influence of 87.5%, but the average percentage error in the calculations was 0.1.

4.5 Conclusion

Observations of phytomass dynamics in a steppe ecosystem in eastern Mongolia confirmed high variability in phytomass resulting from the effects of meteorological factors on productivity. An interpretation of 27 years of field data has allowed us to achieve the main goals of the study: that is, to define the phytocenotic features of the three main plant communities in the eastern Mongolian steppe, to study the dynamics of seasonal plant development in typical steppe communities, to relate phytomass productivity and the structures of the main plant communities in the steppe ecosystem to changes in climatic factors, and to reveal the main trends in plant cover for the observation period in relationship with natural and anthropogenic factors.

Our results suggest the following findings:

1. In all communities, the phytomass accumulation process was described by a polynomial equation with high determination factors (0.98, 0.994, and 0.90, respectively).

2. There was a negative relationship between spring (IV + V + VI) precipitation and the period required to reach maximum phytomass in all three communities ($r = -0.64$, -0.75, and -0.63, for the *Filiformis*, *Elymus*, and *Stipa* communities, respectively). Thus, in years with wet springs, maximum green biomass was attained more quickly than in years with drier springs.
3. Precipitation and temperature did not have immediate effects on phytomass; rather, 10–30 days were required for these factors to impact growth.
4. The green phytomass seasonal dynamics were defined by the integral amount of precipitation and temperature during the vegetative growth period and were described by multivariate linear equations ($R^2 = 0.92$, 0.79, and 0.87).

References

Badarch N. Climate of Mongolia. UB. 1971. 205 pp.

Dashnyam B. Flora and vegetation of Eastern Mongolia. UB. 1974. 146 pp.

Kasimov N.S., Klige R.K. The problems global change. Modern global change the natural ambience. In 2 vol. Vol. 1. -Moscow. Scientific world. 2006. P. 19–34

Lavrenko E.M. About vegetation of the steppes and desert MPR // Problems mastering desert. 1978, #1. P. 3–18.

Liepa I. Ya. To estimation mathematical model. Uch. Zap. Latv. Gos. Univ. 1973. Vol. 181. P. 70–76.

Timofeev D.A. Geomorphological map of Tumentsogt sum., 1984.

Tsegmid Sh. Physical geography of Mongolia. UB. 1968. 405 pp.

Yunatov A.A. The main line of the vegetable cover of the Mongolian Public Republic. Works Mongolian Commissions AS SSSR. Issue 39. 1950. 223 pp.