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Estimation of Grassland Production in Central and Eastern Mongolia from 2006 to 2015 via Remote Sensing

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Abstract: Mongolia is an important part of the Belt and Road Initiative "China-Mongolia-Russia Economic Corridor" and a region that has been severely affected by global climate change. Changes in grassland production have had a profound impact on the sustainable development of the region. Our study explored an optimal model for estimating grassland production in Mongolia and discovered its temporal and spatial distributions. Three estimation models were established using a statistical analysis method based on EVI, MSAVI, NDVI, and PsnNet from Moderate Resolution Imaging Spectroradiometer (MODIS) remote sensing data and measured data. A model evaluation and accuracy comparison showed that an exponential model based on MSAVI was the best simulation (model accuracy 78%). This was selected to estimate the grassland production in central and eastern Mongolia from 2006 to 2015. The results show that the grassland production in the study area had a significantly fluctuating trend for the decade study; a slight overall increasing trend was observed. For the first five years, the grassland production decreased slowly, whereas in the latter five years, significant fluctuations were observed. The grassland production (per unit yield) gradually increased from the southwest to northeast. In most provinces of the study area, the production was above 1000 kg ha^{-1}, with the largest production in Hentiy, at 3944.35 kg ha^{-1}. The grassland production (total yield) varied greatly among the provinces, with Kent showing the highest production, 2341.76×10^4 t. Results also indicate that the trend in grassland production along the China-Mongolia railway was generally consistent with that of the six provinces studied.

Key words: grassland production; MODIS; remote sensing; estimation model; Mongolia

1 Introduction

The world grassland areas account for approximately 25% of the total land area (Fu, 2011), and are the basis for the development of animal husbandry. Grassland is a significant part of the terrestrial ecosystem and plays an important role in climate regulation, wind and sand fixation, and conservation of water and soil (Li et al., 1998; Xu et al., 2008). Mongolia is a typical grassland animal husbandry country. However, in recent years, owing to natural factors and human activity, local grasslands have shown a degrading trend, and the grassland ecological environment has been seriously threatened. Moreover, Mongolia is an important part of the Belt and Road Initiative "China-Mongolia-Russia Economic Corridor" (National Development and Reform Commission,

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2016). Timely and accurate monitoring as well as understanding the temporal and spatial distribution of grassland production are of great significance for the scientific management of Mongolian grasslands and the sustainable development of the resource environment of the "China-Mongolia-Russia Economic Corridor."

Traditional grassland monitoring methods, such as mowing, are mainly based on field investigations, which are costly and time consuming. In addition, monitoring is challenging in areas with poor natural conditions. Compared with traditional methods, remote sensing methods achieve rapid, timesaving, and laborsaving monitoring of grassland production (Xu et al., 2008; Lv et al., 2017), especially for large regional areas. Related research, both domestic and foreign, has been carried out in the field. As early as the last century, Tucker et al. (1985) studied the aboveground biomass in northern Senegal and found a correlation between it and National Oceanic and Atmospheric Administration (NOAA) satellite data, thereby gathering the biomass information of the region from 1980 to 1984. Todd et al. (1998) established an exponential model using Landsat TM imagery to monitor the aboveground biomass in eastern Colorado, USA, and found that the red band is more sensitive to green vegetation and more suitable for biomass estimation. With the launch of the TERRA and AQUA satellites, MODIS data are gradually becoming more widely used. Xu et al. (2009) established a monitoring model between the vegetation index and biomass using MODIS-NDVI data and ground survey data, and estimated the grassland production in Northeast China in 2007. Jin et al. (2011) established an estimation model using MODIS- NDVI data and ground sample data for grassland production in Inner Mongolia Xilin Gol, and obtained the temporal and spatial changes of grassland production in 2005–2009. Fu et al. (2013) used different resolutions of MODIS-NDVI and EVI products to monitor the grassland production in Sichuan, and found that higher resolution (for the same type of remote sensing products) leads to more accurate estimation results. Liu et al. (2018) used the MODIS-NPP data from 2000 to 2010, precipitation and temperature data from April to September in the same period to establish estimation models for different types of natural grassland. They used these models to estimate the grassland production in the three-river headwater region. Qiao et al. (2018) estimated the grassland production in Sunan County, Gansu Province in 2012–2016 using ground monitoring data and MODIS-NDVI/EVI data, and analyzed its temporal and spatial trends. Zhang (2018) used MODIS-NDVI and ground sample data to establish estimation models for different types of grassland in Xinjiang Province, and estimated grassland production in 2015.

Notwithstanding the research that has been conducted on regional grassland production, research on grassland production in the Mongolian Plateau, particularly in Mongolia, is still insufficient. In the context of the current implementation of the Belt and Road Initiative and the construction of the China-Mongolia-Russia Economic Corridor (National Development and Reform Commission, 2015), strengthening the research on remote sensing estimation of grassland production in Mongolia is necessary.

In this study, we selected six provinces in central and eastern Mongolia as the research area, chose four kinds of remote sensing data products, and combined ground survey data and meteorological data to establish three models based on linear, multivariate linear, and exponential functions. Based on an accuracy evaluation, we selected the optimal model for estimating grassland production most suitable for the high altitude and arid environment, and studied the temporal and spatial distribution of grassland production in the region.

2 Study area

The six provinces in central and eastern Mongolia selected as the study area include Overhangay, Dundgovi, Tov, Ulaanbaatar, Govisumber, and Hentiy (Fig. 1). The study area is located at 101°05′–112°43′ E, 44°03′–49°24′ N, bordering Russia in the north and the Gobi region of Mongolia in the south. It is the hinterland of the Mongolian Plateau. The average elevation of the study area is approximately 1400 meters. It is hot in summer and cold in winter, with a large temperature difference between day and night, and between seasons. The sparse precipitation is mainly concentrated in the summer. It experiences a typical continental temperate grassland climate. The population of the study area is approximately 1.78 million, accounting for more than half of the total population of Mongolia. The area is nearly 30.76×10^4 km^2, accounting for 19.6% of the total area of Mongolia. In 2017, the number of livestock here was 19.29 million, accounting for approximately 30% of the total amount in Mongolia.

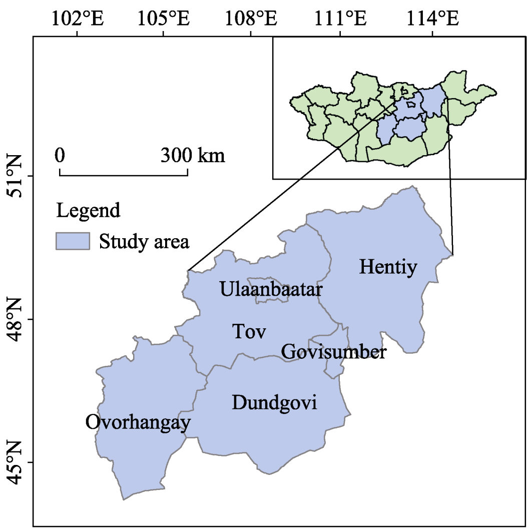

Fig. 1 Location of the study area

3 Materials and methods

3.1 Data sources and preprocessing

(1) Remote sensing data

The remote sensing data are the MOD13Q1 and MOD17A2H data products from the National Aeronautics and Space Administration (NASA) of the United States, from 2006 to 2015. MOD13Q1 has a time resolution of 16 days and a spatial resolution of 250 m. MOD17A2H has a time resolution of 8 days and a spatial resolution of 500 m. MODIS data products have been pre-processed to account for atmospheric correction, geometric correction, radiation correction, and cloud removal. The remote sensing data was formatted and converted by MODIS Reprojection Tools (MRT) software from the original HDF format into TIFF format and set up for Universal Transverse Mercator (UTM) projection.

(2) Ground survey data and statistical data

The sampling time of grassland biomass was August 2013 and August 2014, periods of vigorous vegetation growth. The fresh weight data of the pasture was collected by the ground mowing method. Three sample squares (0.5 m × 0.5 m) were randomly arranged near each sampling point, the average value of the three squares was taken as the measured value of the sampling point, and the coordinates of the sampling point were recorded by GPS. The measured sample coordinate data and the fresh grass yield data were standardized, and the point layer was generated by ArcGIS software. A total of 29 samples were collected (as shown in Table 1), of which 23 samples were used for modeling and 6 for model validation.

The population and livestock data of the study area were collected from the official website of the National Statistics Office of Mongolia (National Statistics Office of Mongolia, 2018), and the grassland type and meteorological data (year-by-year) were provided by National University of Mongolia. Meteorological station data were interpolated by ArcGIS software into mean annual temperature and precipitation data for Mongolia.

3.2 Methods

(1) Vegetation index calculation

Based on the characteristics of the study area, four indices—NDVI, EVI, MSAVI, and PsnNet—were selected to estimate the grassland production. Different indices are modeled separately. NDVI and EVI were derived from MOD13Q1 data products, and PsnNet is derived from MOD17A2H data products. MSAVI was calculated by RED band and NIR band, and its calculation formula is as follows:

$$MSAVI = \frac{2\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR} + 1)^2 - 8(\rho_{NIR} - \rho_{RED})}}{2} \quad (1)$$

where ρ_{NIR} is the near-infrared band reflectance and ρ_{RED} is the red band reflectance.

Table 1 Ground survey data

Number	Latitude (N)	Longitude (E)	Fresh weight of grass (g)
1	47.9721°	106.5823°	56.7
2	47.6294°	106.9654°	45.0
3	47.4334°	106.9728°	75.0
4	47.8030°	107.5299°	45.0
5	47.6933°	108.5277°	41.7
6	47.4661°	109.5361°	53.3
7	47.2799°	110.8333°	123.3
8	47.3462°	111.5222°	100.0
9	46.3005°	108.4715°	33.3
10	46.6880°	108.0976°	38.3
11	47.7360°	106.8914°	48.0
12	47.6222°	106.8917°	29.3
13	47.3096°	106.6711°	32.7
14	46.9239°	106.6290°	52.7
15	46.5641°	106.5309°	27.3
16	46.2120°	106.4173°	26.7
17	45.8025°	106.3062°	10.0
18	45.4868°	106.7585°	8.7
19	45.1543°	105.5664°	7.3
20	44.7918°	105.5927°	4.0
21	45.4658°	101.1738°	15.3
22	45.7006°	101.3769°	21.3
23	45.8073°	101.7643°	59.3
24	45.9798°	102.1687°	34.0
25	46.1417°	102.6169°	38.0
26	46.5678°	103.0513°	71.3
27	46.8410°	103.3977°	21.3
28	47.1718°	103.6255°	22.0
29	47.5747°	104.7149°	37.3

(2) Model building and accuracy verification

The study area is located at a high altitude and is greatly affected by climatic conditions, especially precipitation. We considered meteorological factors and established a multivariate linear model based on the linear and exponential models. For the ground sample data collected in 2013 and 2014, we used the Geographic Information System (GIS) methodology to extract the values of remote sensing data and meteorological data for the year corresponding to the grassland production data. We used SPSS statistical software to perform regression analysis on the remote sensing, meteorological, and grassland production data. This established a grassland production estimation model with remote sensing data and meteorological data as independent variables.

After an F-test of the estimation model, the optimal model was selected according to the decision coefficient R^2 of of the equation and the accuracy of the evaluation result. The randomly selected 20% sample data were used as verification data, and the accuracy of the model was evaluated by the average relative error and root-mean-square error. They are defined as follows:

$$REE = \frac{\sqrt{\frac{\sum_{i=1}^{N}(Y_i - Y_i')^2}{N}}}{\overline{Y_i}} \times 100\% \quad (2)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Y_i - Y_i')^2}{N}} \times 100\% \quad (3)$$

where *REE* is the average relative error, *RMSE* is root-mean-square error, N is the number of samples, Y_i is the measured grassland production in g m^{-2}, Y_i' is the estimated grassland production in g m^{-2}, and $\overline{Y_i}$ is the average measured grassland production in g m^{-2}.

4 Grassland production estimation results

4.1 Estimation model

The correlation between grassland production and remote sensing data, mean annual temperature, mean annual precipitation, and DEM data was analyzed by SPSS software (as shown in Table 2). The results show a highly significant correlation between grassland production and the four remote sensing indices, followed by mean annual precipitation. The correlation between mean annual temperature and grassland production is relatively weak, and there is no significant correlation between DEM and grassland production.

In addition to the remote sensing data, we selected the precipitation data to participate in the model building, based on the results of the correlation analysis in Table 2, and established three regression models for the four types of remote sensing indices, as shown in Table 3. The results show that all the models pass the extreme significance test ($P < 0.01$). R^2 in the table is the coefficient of determination; the closer it is to 1, the better the fit is to the model. The comparison shows that the exponential model based on MSAVI has the best fit, with an $R^2 = 0.72$. The model accuracy was verified by the reserved samples. The results show that there is a good correspondence between the estimated data of grassland production and the measured data based on the exponential model of MSAVI, with an RMSE of 279.09 kg/hm^2 and model accuracy of 78%. This is suitable for the study of grassland production estimation in this study area.

4.2 Spatial and temporal distribution characteristics of grassland production

Based on the above analysis, the optimal model for grassland production estimation in the study area is an exponential model based on MSAVI (250 m spatial resolution), Y=3.594exp (5.224X). The spatial distribution of annual grassland production in the study area from 2006 to 2015 was obtained by inversion of the optimal model (as shown in Fig. 2).

Table 2 Correlation analysis between grassland production and impact factors

Element	Precipitation	Temperature	DEM	EVI	MSAVI	NDVI	PsnNet
Correlation coefficient	0.645**	−0.477*	0.108	0.762**	0.804**	0.798**	0.856**
P value	0.001	0.022	0.625	0.000	0.000	0.000	0.000

Note: ** When the confidence is 0.01, the correlation is significant; * When the confidence is 0.05, the correlation is significant

Table 3 Grassland production estimation models based on remote sensing

Parameter	Model type	Inversion model	R^2	*Sig.*	RMSE (kg ha^{-1})	Accuracy (%)
EVI	Linear model	$Y = -19.490+384.791X_1$	0.46	0.000	423.55	66
	Exponential model	$Y = 4.257\exp(12.647X_1)$	0.63	0.000	466.53	63
	Multivariate model	$Y = -16.655+436.870X_1 - 0.049X$	0.47	0.002	423.91	66
MSAVI	Linear model	$Y = -27.370+165.323X_2$	0.57	0.000	370.00	71
	Exponential model	$Y = 3.594\exp(5.224X_2)$	0.72	0.000	279.09	78
	Multivariate model	$Y = -18.070+239.539X_2 - 0.177X$	0.61	0.000	383.40	70
NDVI	Linear model	$Y = -13.940+204.158X_3$	0.56	0.000	335.37	73
	Exponential model	$Y = 5.728\exp(6.300X_3)$	0.68	0.000	306.68	76
	Multivariate model	$Y = -3.192+264.166X_3 - 0.119X$	0.59	0.000	308.76	75
MOD17A2H PsnNet	Linear model	$Y = 0.482+0.403X_4$	0.68	0.000	389.21	69
	Exponential model	$Y = 12.701\exp(0.010X_4)$	0.66	0.000	322.82	74
	Multivariate model	$Y = 16.944+0.481X_4 - 0.106X$	0.70	0.000	375.42	70

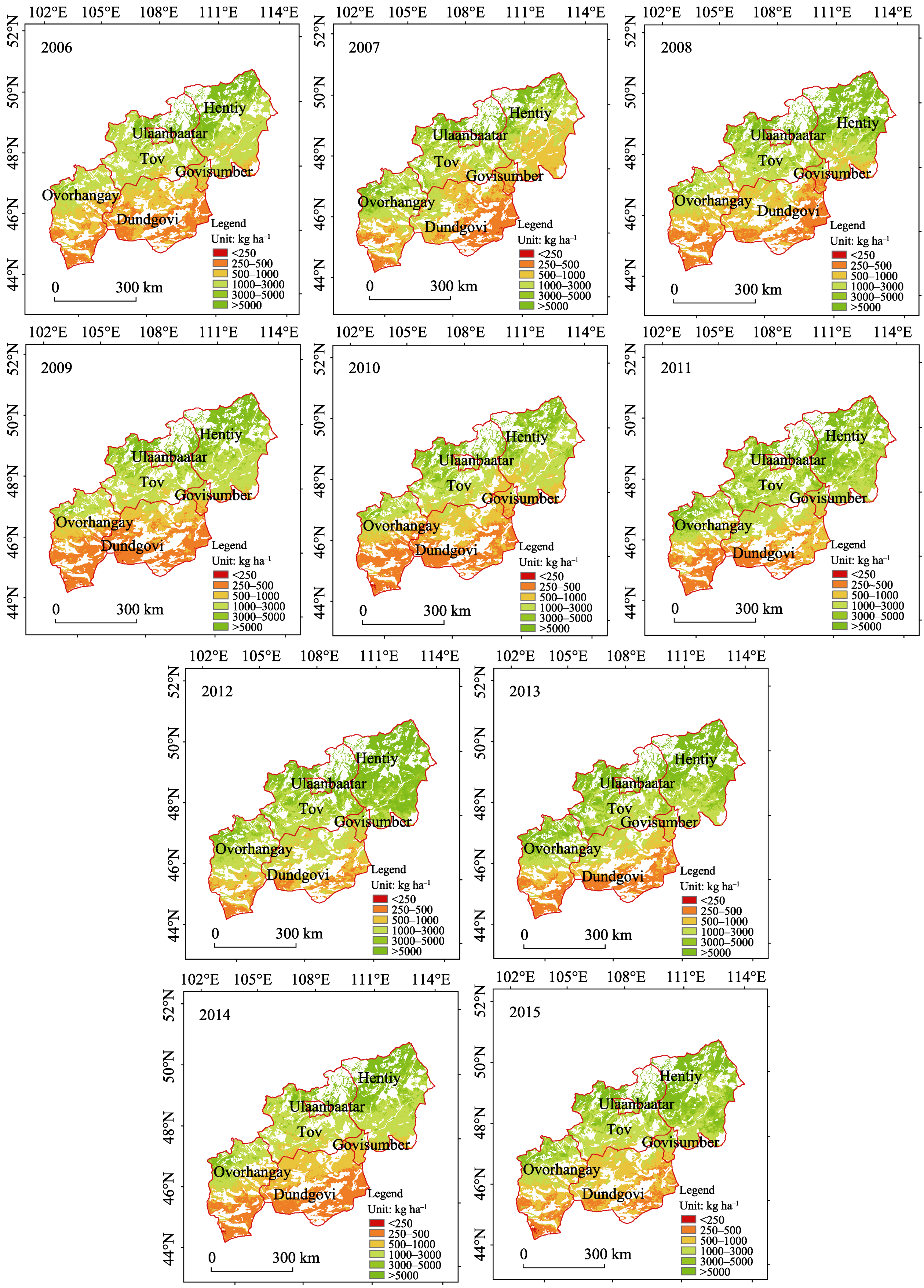

Fig. 2 Spatial distribution of grassland production in the study area from 2006 to 2015

4.2.1 Spatial distribution

Fig. 2 shows that the grassland production in the study area has obvious spatial distribution differences, showing an increasing trend from southwest to northeast. The average grassland production (per unit yield) of Hentiy and Tov provinces, and Ulaanbaatar City in the north was higher than 3000 kg ha^{-1} over the 10-year study period, which was greater than the average grassland production of the six provinces in the study area (2470.32 kg ha^{-1}). In the three southern provinces, the Overhangay Province had a relatively high grassland production (per unit yield), which was greater than 1500 kg ha^{-1}, followed by the Govisumber Province, 1213.99 kg ha^{-1}, whereas Dundgovi Province had the lowest grassland production, less than 1000 kg ha^{-1}.

4.2.2 Temporal distribution

The variation in grassland production over time is shown in Figure 3. The grassland production in the study area fluctuated significantly between 2006 and 2015. The 10-year average grassland production (total production) was 5261.8 × 10^4 t, the peak grassland production was observed in 2012 at 7282.39 × 10^4 t, and the lowest grassland production, achieved in 2010, was 3949.39 × 10^4 t. During the first five years, grassland production showed a downward trend, with the annual grassland production below the 10-year average. During the latter five years, grassland production fluctuated greatly and was higher than the 10-year average in four of the five years. Overall, the grassland production increased slightly.

4.3 Variation characteristics of grassland production along the China-Mongolia railway

The Mongolian section of the China-Mongolia Railway is located in the central and eastern part of Mongolia. We considered a 200-km wide buffer zone along the Mongolian section of the railway as the target area, and used the optimal model obtained from the study to invert the grassland production of this region in 2006–2015. The trend of the grassland production changes was analyzed pixel-by- pixel using linear regression analysis (Wang et al., 2016), and an interannual variation chart of grassland production from 2006 to 2015 was obtained (Fig. 4).

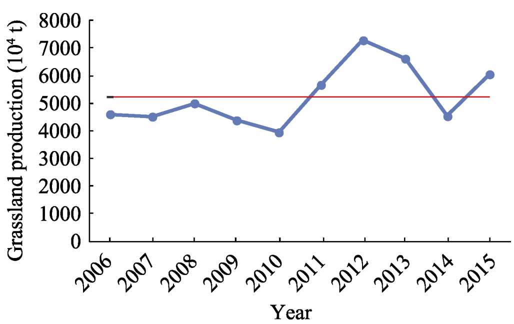

Fig. 3 Annual grassland production in the study area from 2006 to 2015

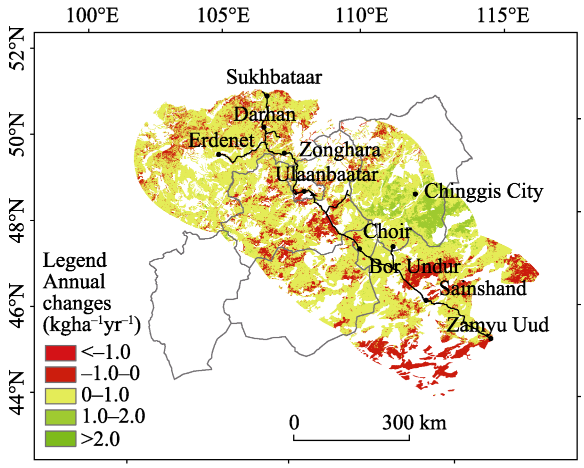

Fig. 4 Interannual variations in grassland production along the China-Mongolia railway

A positive change rate in the figure indicates that grassland production is on the rise, and vice versa. The rate of change of grassland production in most areas along the China-Mongolia Railway is greater than 0 kg ha^{-1} yr^{-1}, mainly between 0 and 1 kg ha^{-1} yr^{-1}, which indicates that grassland production increased as a whole. Green patches appear in the central and western parts of the Hentiy Province and in the eastern part of the Tov Province, indicating that grassland production in this area increased rapidly. Grassland production in the southern region, the Dundgovi Province, mainly showed a decreasing trend. In some areas near the railway, grassland production obviously decreased, such as the southern portion of Ulaanbaatar, the southeastern part of the Tov Province, and the northwest region of the Govisumber Province.

5 Discussion

5.1 Selection of vegetation index

A vegetation index is the simplest and most effective measure of surface vegetation status (Guo, 2003). Different vegetation indices have different advantages. However, their accuracy differs even when used for plant biomass estimation in the same area. Because of the differences in topography and elevation in different research areas, vegetation indices lack universal applicability (Piao et al., 2004; Zhang et al., 2012). Therefore, there are some shortcomings in using a single vegetation index to estimate grassland production. Presently, most studies are based on NDVI for grassland production estimation. It is sensitive to soil background and is not suitable for estimation of semi-arid ecosystem biomass (Jacques et al., 2014). In this study, we selected NDVI, EVI, MSAVI, and PsnNet for modeling. Among them, MSAVI was the most suitable for different vegetation coverage and soil underlying surfaces, and can eliminate or reduce the noise of the soil background. The results of our study showed that the fitting of MSAVI was better than that of NDVI, PsnNet, or EVI. Thus, the vegetation index was more suitable for the estimation of grassland production in central and eastern Mongolia.

5.2 Grassland production estimation model

Numerous studies have shown that biomass changes are significantly correlated with climatic factors. Precipitation is an important indicator affecting biomass in arid and semi-arid areas (Piao et al., 2006; Park et al., 2010; Song et al., 2011). In recent studies, the estimation of biomass has been mostly based on a statistical model between remote sensing data and ground measured data, which fails to fully consider the impact of climate factors on grassland production in their entirety. In this study, vegetation index and PsnNet data were used to establish linear and exponential regression models. On this basis, precipitation data was included in the regression model and a multiple regression analysis was performed. The optimal model was an exponential model based on MSAVI, with an accuracy of 78%, R^2 of 0.72, and a relative error of 22.15%. Among the various models, the one-dimensional linear model had the lowest accuracy, 69.75%, and the accuracy of the exponential model and multi-linear model were not considerably different, 72.75% and 70.25%, respectively. However, the R^2 of the exponential model was 0.67, which was significantly higher than 0.56 for the one-dimensional linear model and 0.59 for the multi-linear model. Compared with the one-dimensional linear model, the exponential model and multi-linear model were more suitable for grassland production research in this region.

5.3 Grassland production estimation result

There have been few studies on grassland production in Mongolia, mostly on biomass in the southern Mongolian Plateau, Inner Mongolia in China, and other places, or the macroscopic vegetation coverage of the Mongolian Plateau. Batunacun et al. (2015) studied the spatial distribution pattern of grassland plants along the Ulaanbaatar to Xilinhot and found that the number of plant species from Ulaanbaatar to the Tov and Dundgovi provinces decreased gradually. Zhang et al. (2018) found that the spatial distribution of vegetation coverage on the Mongolian Plateau was gradually decreasing from northeast to southwest, which is consistent with the spatial distribution of grassland production in this study. Bao et al. (2006) studied the changes in vegetation coverage on the Mongolian Plateau through MODIS-NDVI data and found that the vegetation coverage in the Tov Province of Mongolia and Ulaanbaatar City decreased significantly during 2001–2010, which is consistent with the annual change of grassland production for the corresponding period in this study. Wendurina et al. (2017) analyzed the spatial and temporal changes of vegetation cover in the Mongolian Plateau from 2000 to 2014 and found that the vegetation cover showed an overall improvement trend. The trend in vegetation cover change is consistent with the trend in grassland production in our study area.

5.4 Driving force analysis

The temporal and spatial distribution characteristics of Mongolian grassland production are driven by multiple factors. The study area is located in the middle and eastern part of the Mongolian Plateau. It has a typical temperate continental climate, i.e., arid, little precipitation, and sensitive to climate change. Water is the main factor affecting grassland biomass in this area. Precipitation can supplement the water needed for plant growth and reduce the surface temperature. The results show that there is a positive correlation between grassland production and precipitation, and the fluctuation curve of grassland production is the same as that of precipitation. The precipitation in the study area was above 170 mm over the ten years of the study. The precipitation decreased significantly in 2010, and grassland production during that year was the lowest. In 2012, precipitation was the most abundant, with corresponding maximal grassland production. Dai (2014) and Zhou et al. (2014) showed that precipitation is an important factor affecting the changes in vegetation cover in the Mongolian Plateau. They showed that NDVI was positively correlated with precipitation in most areas, which was consistent with the results of this study.

In addition to natural factors, anthropogenic factors also affect grassland production in the study area. Animal husbandry is a traditional industry in Mongolia; however rough management methods that pursue economic interests can cause damage to the grassland ecosystem. Mongolia's policy that the grazing land is owned by the general population, who has free choice of residence also encourages overload in the region (2012). In recent years, with the increase in the number of livestock in Mongolia, especially because of the strong demand in the cashmere market, the number of goats has increased considerably, which has a certain impact on the quality and yield of the pasture. As in 2009, the number of goats in the study area have continued to increase, reaching 5.05 million. During this period, the grassland production in the region showed a downward trend. In 2010, the number of goats suddenly decreased, and the grassland production in the next year showed a rebound. Human activity can also reduce the quality and yield of pasture by utilizing and rehabilitating land. Although the average population density of Mongolia is low, the available land is relatively small. The population of the study area increased from 1.37 million to 1.73 million during 2006–2015. When the existing land is unable to meet the needs of the growing population, land cover will change under the population influence, resulting in changes in the grassland area and, in turn, grassland production.

Our study found that grassland production along the Mongolian section of the China-Mongolia Railway increased during the study period, and the overall trend in grassland production along the railway was consistent with the six provinces in the study area. There is no evidence that the railway has had an impact on the grassland. However, with the construction of the China-Mongolia-Russia Economic Corridor, the grassland production in the region should be continuously monitored and analyzed. Policy recommendations can be timely proposed according to the monitored situation.

6 Conclusions

To study the spatial and temporal distribution and change in grassland production in the high-altitude areas of central and eastern Mongolia, based on EVI, MSAVI, NDVI, and PsnNet data, we established three models by statistical regression to estimate the grassland production in the study area. In 2006–2015, the high-yielding areas for grassland production of the six provinces in the study area were mainly concentrated in the northeast, and the low-yielding areas were mainly concentrated in the southwest. Grassland production changed little in the first five years and showed a steady decline overall, whereas it fluctuated greatly in the last five years and showed a slight overall increase. The trend of the change in grassland production along the Mongolian section of the China-Mongolia Railway in the study years was the same as that of the six provinces, with an overall slight increase. The fluctuation in grassland production is caused by a combination of natural and anthropogenic factors. The influence of precipitation was particularly significant for grassland production; meanwhile, human activity has had a significant effect as well, manifested as direct and indirect damage to the grassland.

To a certain extent, this study has counteracted the lack of research on grassland production in Mongolia. However, limited by geography and the field-working environment, the study area included only six provinces in the central and eastern parts of Mongolia; the grassland production status of the entire country was not addressed in the sudy. Therefore, future research can strengthen grassland monitoring in other parts of Mongolia and improve the accuracy of estimation by increasing the number of sampling points. In addition, the relationship between grassland production and meteorological factors needs to be further studied to analyze the effects of temperature, precipitation, and other meteorological factors on grassland production at different time scales.

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蒙古国中东部地区 2006–2015 年产草量遥感估算研究

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摘 要：蒙古国是“一带一路”倡议“中蒙俄经济走廊”的重要组成部分，也是受全球气候变化影响显著的区域，草地产草量的变化对该地区可持续发展具有深远影响。本文探索适合于蒙古国地区特征的产草量估算最优模型，并对该地区产草量时空分布进行研究。基于 EVI、MSAVI、NDVI 和 PsnNet 四种遥感指数，结合地面观测资料，通过统计分析方法建立三种产草量估算模型。在模型评价基础上，选择模拟效果最好的基于 MSAVI 的指数函数模型（模型精度 78%），完成 2006−2015 年蒙古国中东部 6 省产草量估算。结果表明，研究区 10 年间产草量具有明显的波动趋势，前 5 年产草量缓慢下降，后 5 年则波动较大，总体略呈上升趋势。研究区产草量（单产）自西南向东北呈逐渐增加的趋势，大部分省份单产均在 1000 kg ha^{-1} 以上，最大单产地区为肯特省，3944.35 kg ha^{-1}；各省产草量（总量）差异较大，其中肯特省的产草量（总量）最高，为 2341.76×10^4 t。研究同样发现，中蒙俄铁路沿线产草量变化趋势与研究区 6 省基本一致。

关键词：产草量；MODIS；遥感；估算模型；蒙古国