The changing patterns in grasslands and soil fertility along the Eastern Eurasian Steppe Transect across China – Mongolia – Russia

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Abstract. This paper analyses the adaptation and change in species along the north-south Eastern Eurasian Steppe Transect across China – Mongolia – Russia and considers the implications for climate change and management. The plant community diversity, above-ground biomass, N:P ratios of community and of dominant species, soil N (nitrogen), soil P (phosphorus) and AP (available phosphorus) contents were studied along a 1400 km north-south transect. The main findings were: (1) the community diversity and productivity decreased with the increase in latitude and a significant negative correlation was found between the many plant characteristics and latitude ($P < 0.05$) – decreasing diversity, biomass and N:P ratios; (2) soil AP content was lowest in Inner Mongolia, whereas no significant change in soil total P with latitude was found in China-Mongolia-Russia transect, a significant positive correlation was detected between the soil nutrient (N and AP) and latitude ($P<0.05$); (3) a significant positive correlation was evident between plant community P content and soil AP content ($P<0.01$), but a negative correlation was found between community N:P ratio and soil AP content ($P<0.05$). The soil AP content can be used as a soil properties indicator to reflect the plant communities P content and N: P ratio. It is suggested that greater human activities in Inner Mongolia may be an important factor affecting soil AP content, community N:P and plant growth.

Keywords: Grassland, soil, vegetation, nitrogen, phosphorus.

Introduction

The Eurasian steppe is the world's largest landscape of interconnected grassland ecosystems, widely used for livestock and for wildlife, but under considerable pressure from increasing utilisation by man, and environmental pressures such as climate change. The same and closely related species occur across parts of the landscape and are subject to varying local influences. The reactions of species to changing conditions along a transect can provide some insight into how factors such as climate, vegetation, soil and human activities, affect species behaviour. Ecological transects are an effective way to explore the relationship between terrestrial ecosystems and climatic trends today and thence infer likely trends in the future. But that requires the separation of climate trends from local soil, management and other factors. The power of this approach has long been recognized. The International Geosphere Biosphere Program (IGBP) identified terrestrial transects around the globe that could be used for this purpose (Steffen *et al.* 1992; Canadell 2001). The study of Chinese domestic transects was started in 1995, investigating a south-north transect in eastern China mostly influenced by temperature (Teng *et al.* 2000) and another more influenced by moisture in north-east China (Oren *et al.* 2001; Pepin and Korner 2002; Zhang and Yang 1995).

The Eurasian Steppe at high latitudes is in one of the most sensitive and vulnerable areas for climate change, and one of the more ecologically degraded regions due to the effect of human activities (Hou 2012). Little information is available to adequately understand and then predict likely impacts of climate change across regions. In order to better understand the change and driving factors of the Eurasian temperate grassland ecosystem and to provide a scientific basis and a feasible way on the scientific management of grasslands, the Grassland Research Institute, Chinese Academy of Agricultural Sciences developed the first ever long transect study across China - Mongolia - Russia, the Eastern Eurasian Steppe Transect (EEST) (Hou 2012). The transect has an obvious thermal gradient due to alternate effect of the East Asian monsoon and the northern cold snap, has a continuous distribution of similar vegetation, some common elements in soils of the eastern Eurasian steppe, grazing gradients across different countries and differing human and livestock management practices. Such a study has important scientific and practical guidance value for sustainable grassland management (Fig. 1A).

This paper focuses on general aspects of ecosystem

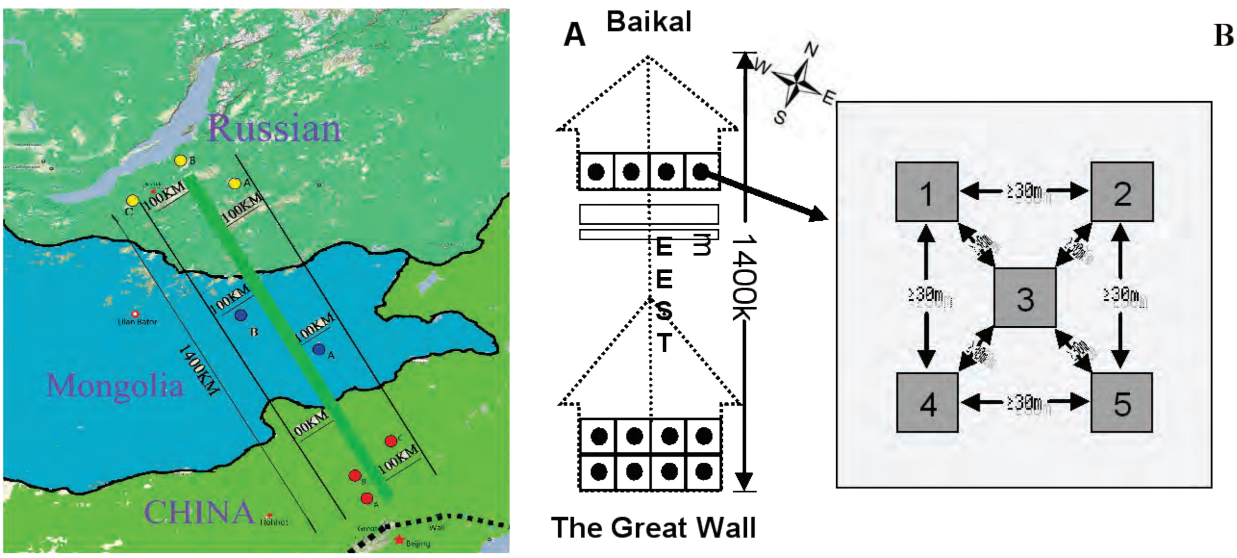

Figure 1. The location of 1400 km Eastern Eurasian Steppe Transect (EEST), sample sites and transect and sampling quadrat design.

structure and function changes along the transect in July through September 2012, including climate, grassland vegetation type, structure, productivity, species diversity and soil nitrogen and phosphorus levels. The EEST team also investigated a series of other factors that will be reported elsewhere: (1) the response of grassland ecosystem structure, functional changes, stoichiometrics, and biodiversity distribution patterns to varying climates; (2) genetic diversity, tolerance and adaptive mechanisms of main plant species to varying stress; (3) the effects of different grazing use patterns and intensity; and (4) the effect of land use/cover change on ecosystem status and function.

Research methods

Study region

EEST is a transect from the Great Wall of China (south) through Mongolia to Lake Baikal (north) in Russia (41.55º–52.63ºN, 105.53º–117.17ºE, 480-1647 m a.s.l.); 1400 km from south to north and 200 km wide from east to west. Mean annual air temperatures vary from -2.5ºC to 2.8ºC with an average annual precipitation of 170-340 mm. The Inner Mongolia study area has a semi-arid continental temperate steppe climate with the lowest monthly mean temperature in January (-21.4ºC) and the highest monthly mean temperature in July (18.0ºC). The region is dry in spring and moist in summer with a long-term average annual precipitation of 279 mm; The Mongolian study area is an extreme continental climate. The average summer temperature is 20.0ºC and in winter is -20.0ºC. Mean atmospheric precipitation in the catchment in winter is 10-50 mm and in summer 300 mm (Marin 2010); Russia has a typical continental climate with a mild summer (mean of 14-22ºC) and cold winter (-18 to -28ºC) (Ren *et al.* 2011). The first frost generally comes in late August. Mean annual precipitation is approximately 300mm. Along the EEST, there is a decline in length of the growing season from around 16 to 12 weeks from south to north, reducing the thermal time for plant growth.

The EEST starts at the northern end of the summer green broad-leaved forests of East Asia, progressing north through various temperate steppes (typical, Mongolian, Central Asian, Siberian) to Eurasian coniferous forests in the Baikal region (Fig. 1A). The main common species occurring over larger parts of the EEST are the grasses *Agropyron critatum* (C3), *Cleistogenes squarrosa* (C4), *Leymus chinensis* (C3), *Stipa grandis* (C3), *S. krylovii* (C3), other monocotyledons *Allium bidentaum*, *Carex duriuscula*, *C. korshinskii*, forbs *Potentilla bifurca*, *Potentilla acaulis*, *Cymbaria dahurica*, and the legume *Caragana microphylla.*

Sampling and measurement

Plots with relatively consistent human disturbance were selected in grasslands along the latitudinal gradient. The data presented were obtained from 20 July to 20 August 2012 on 32 plots in Inner Mongolia, China; 18 plots in Mongolia; and 8 plots in Russia. Due to different times for estimated peak biomass sampling was done in China from 15-20 August, in Mongolia 5-10 August and in Russia 22-27 July (Ren et al. 2011). The entire survey used a transect grid method (length 50km, width 200km) and at least three sample sites were selected within each grid of the survey. Grid set and investigation processes are shown in Figure 1B. The spacing between the plots was about 50km. Five quadrats, each 1 x 1m, were located in each survey plot, and were arranged as a square with one in the centre (Fig. 1B). Coverage, average height and ecotype of all species were recorded in each quadrat. After observation, one-quarter of the plants in quadrats 2 and 4 and all plant species in quadrat 3 were clipped. Above-ground plant tissues (living above-ground biomass and standing litter) were separated from standing litter of previous years in different species, and then collected in a bag and processed in the laboratory to determine the above-ground biomass. About 3-5 dominant species were selected after community characteristics observation in 30×30m of each quadrat; ~50 g was clipped from each dominant species for laboratory analysis. Harvested samples were oven-dried at 65ºC for 48 h and then weighed and ground.

Three layers (0-10 cm, 10-20 cm and 20-30 cm) at the same sites were excavated using a soil auger (5cm in diameter) after the aboveground biomass sampling in quadrat 2, 3 and 4; in each quadrat 3 samples were taken, and then the same layer of soil samples were combined, placed in sealed plastic bags, tagged and analysed in the laboratory. Soil total nitrogen (TN), total phosphorus (P) and available phosphorus (AP) content were determined on the soil samples. Similarly, total plant N and P contents of the sampled plant tops were determined. Soil TN and plant N contents were determined by the semi-micro Kjeldahl nitrogen determination method and the content of soil P and plant P was determined by molybdenum antimony colorimetric method. The content of soil AP was determined using sodium bicarbonate molybdenum antimony colorimetric method (Murphy and Riley 1962). The mean soil P and AP content of 0-30cm was determined by combining the values for layers.

Data analysis

Data were pre-processed using Microsoft Excel 2007 for sorting, calculating sums, averages and for mapping. SAS version 9.0 (SAS Institute Cary North Carolina USA) was used for data inspection and statistical analysis; Duncan's method was used for determining significance. Soil N, P and AP were analysed using one-way ANOVA in between different areas (China, Mongolia and Russia). Relationships between latitude (as a surrogate for thermal differences in climate) and community above-ground biomass, major species dominance, species α diversity (Shannon-wiener index), β diversity (Sorenson index), and community N:P ratio were analysed by using Pearson correlation analysis and regression methods.

Results

Vegetation change along the Eastern Eurasian Steppe Transect (EEST)

There were 121 different species found within 295 quadrats along the 1400 km of transect, of which about 60% of the biomass were *Stipa grandis*, *Leymus chinensis* and *Cleistogenes squarrosa*. Species composition was relatively simple with few weed components. Xerophytic grasses were the dominant species. Above-ground biomass decreased from south to north with the increasing latitude (P<0.001) (Fig. 2).

Summed dominance ratio (SDR_2) of dominant species along EEST

Values for SDR_2 (Fu 2006) for the dominant grasses *Stipa grandis*, *Leymus chinensis*, *Cleistogenes squarrosa* and *Agropyron critatum* tended to be higher at lower latitudes, decreasing at the highest, more northerly sites (Fig. 3). This effect was only significant for *Leymus chinensis.* Overall, the SDR_2 values for *Stipa grandis* and *Leymus chinensis* were the highest in vegetation community of transect, followed by *Cleistogenes squarrosa*, and the lowest was *Agropyron critatum. Stipa grandis* was the typical dominant species along the transect.

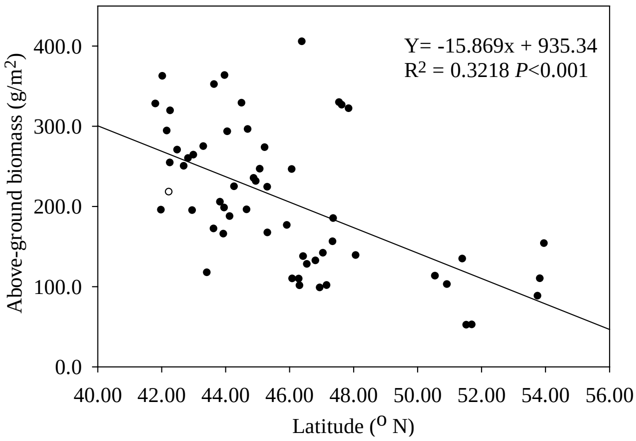

Figure 2. The significant decline in above-ground biomass with higher latitudes along EEST.

The changes of species diversity along EEST

Both the Shannon-Wiener and Sorensen indices had a tendency to decline at higher latitudes, though this was only significant for Shannon-Wiener (Fig. 4A). With increasing latitude, the decrease in the Shannon-Wiener index and above ground biomass (Fig. 2) suggests that diversity declines with productivity.

N and P of community and dominant plants along EEST

The N:P ratio of plants on average, declined with latitude (Fig. 5A); this was significant for *Stipa grandis* and marginally significant for *Cleistogenes squarrosa* where most samples showed this trend, though reasons for the outlying points are not known. *Leymus chinensis* was not detected at greater than latitude 48^{o} in this survey.

Soil N and P content among China, Mongolia and Russia

There was a difference in soil N content in China - Mongolia - Russia regions along the south - north EEST. The soil N content in Mongolia was higher than in China and Russia (P<0.05) and there was no significant difference between China and Russia (Fig. 6A). This consistent higher trend for mean soil N content in Mongolia was detected for 0-10 cm and 20-30 cm. A significant difference was found for soil N content at 10-20 cm between Mongolia and Russia (P<0.05). No significant difference was detected for soil P content in 0-10 cm, 10-20 cm and 20-30 cm samples between China, Mongolia and Russia (Fig. 6B). Soil P content was slightly higher in Inner Mongolia, China than both Mongolia and Russia. The soil AP content in 0-10 cm, 10-20 cm and 20-30 cm layers was lower in China than in Mongolia and Russia (P<0.05 (Fig. 6C). A significant difference in soil AP at 0-10 cm was found between Mongolia and Russia (P<0.05) whereas no significant difference was detected in the 10-20 cm and 20-30 cm layers.

Change of soil N, P and AP along latitude gradient in EEST

Soil N content was lower in the south than in the north (P =

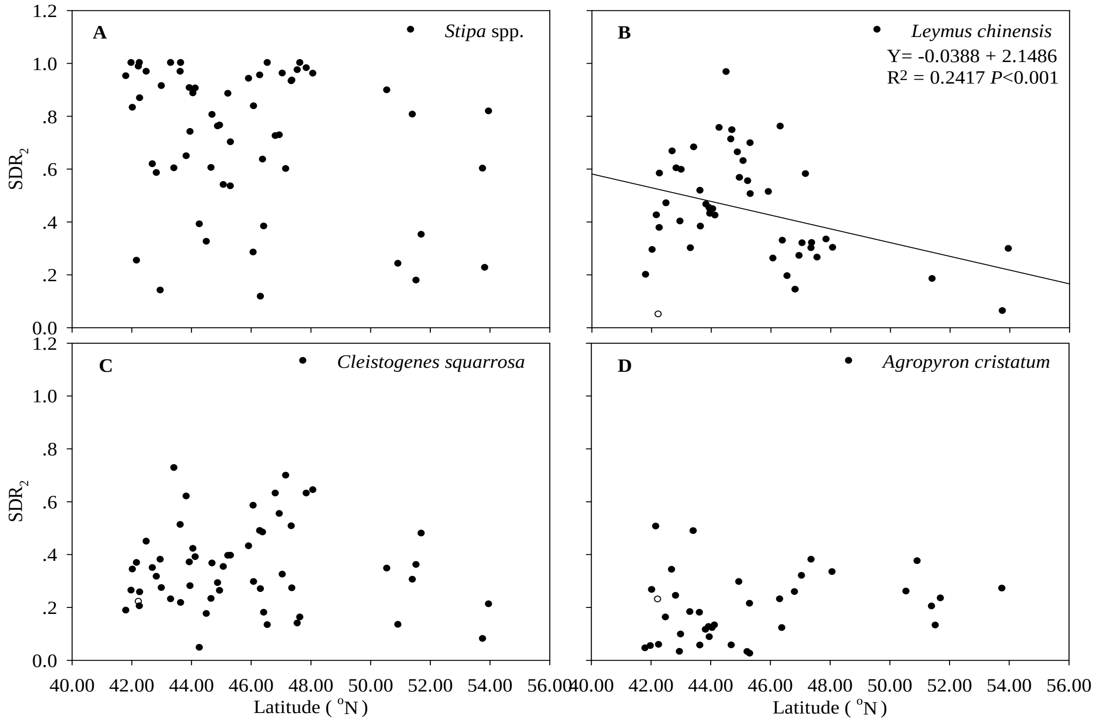

Figure 3. Summed dominance ratio (SDR_2) changes with latitude in EEST for dominant grass species

0.03, Fig. 7A). No significant change was found between total soil P and latitude (Fig. 7B), but soil AP content increased significantly with latitude (Fig. 7C). The average soil AP content was 10.83±0.28 mg/kg in the south (42.0-45.5°N), 29.07±3.76 mg/kg in central areas (45.9°-48.1°N), and 26.14±1.42 mg/kg in the north (50.6°-53.8°N) respectively.

Discussion

Latitude effects on plant species, diversity and productivity

The results presented here show that along this extensive transect the natural variation in temperature and to some extent soil moisture during the growing season, does result in differences in composition of the more dominant grass species, providing some evidence of what may happen in the future. In general plant species richness and diversity indices were greater in the south. The northern areas could then be expected in the future to have increasing plant species diversity with global warming and to be more ecologically stable. This data showed no evidence of reduced diversity in warmer parts of the region. Grassland biomass reduced as latitude increased from Inner Mongolia > Mongolia > Russia, reflecting reduced thermal conditions. The productivity of grasslands in more northerly areas could then be expected to increase with warmer conditions. The evidence that plant species have been affected by climate change in middle and high latitudes during the 20th century (Solomon, 2007) needs to be evaluated in terms of the likely trends. Fertility trends in the short (N) and long-term (P) affect species diversity and composition (Lorenzo *et al.* 2007). The decrease of plant diversity on the most fertile soils could be the consequence of the dominance of few competitors or ruderals, which

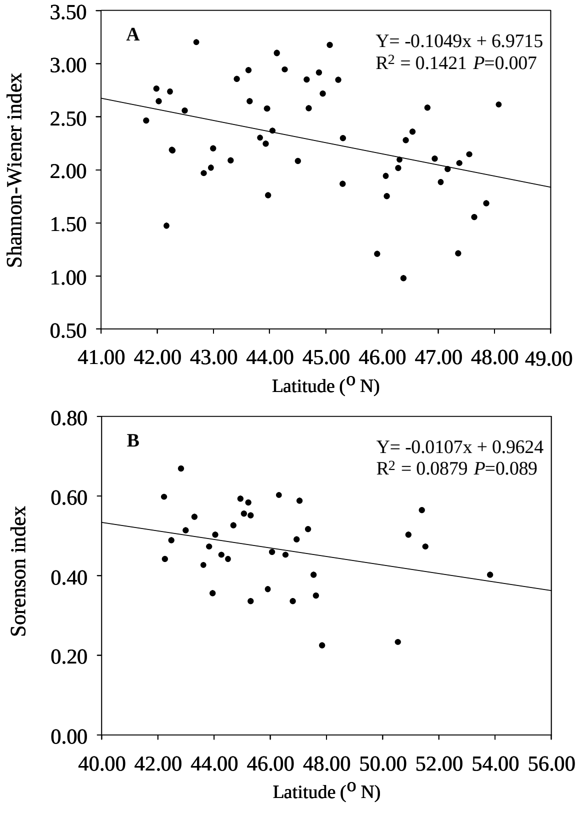

Figure 4. Marginal decline in biodiversity indices with latitude in EEST

prevented the establishment of small stress-tolerant species (Peña-Claros *et al.* 2012). The data suggests northern latitudes could increase in diversity, be more ecologically stable and increase in productivity with global warming. This could be modified by other subtle, unknown effects of precipitation, which are not yet clear.

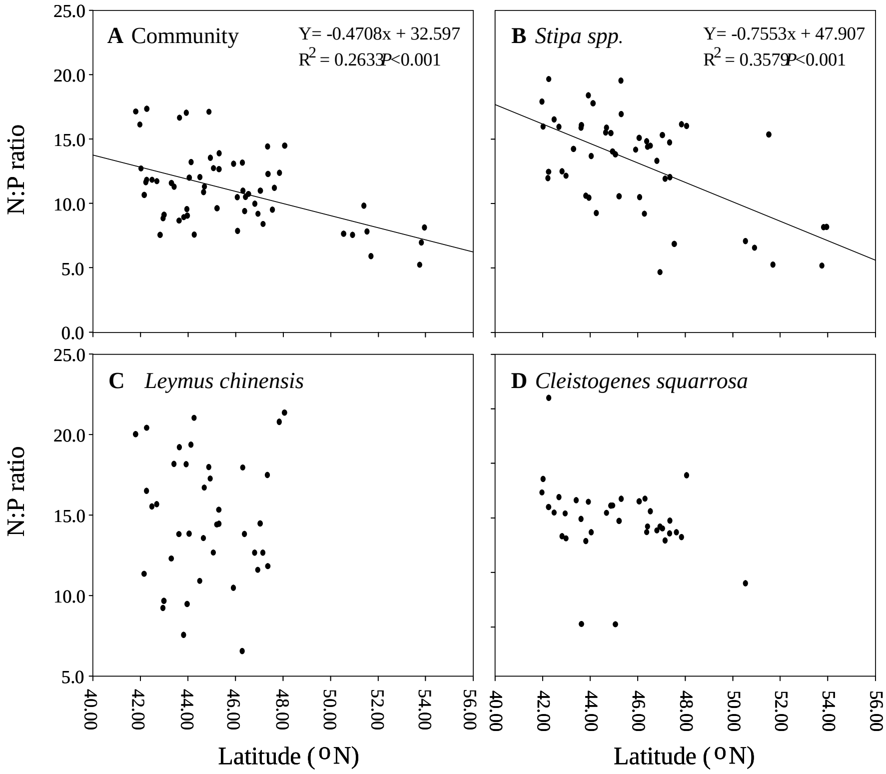

Figure 5. Plant N:P ratios with latitude for the grassland community and three dominant perennial grass species along the EEST

The evidence that *L. chinensis* is not currently at the highest latitudes surveyed could suggest that as global temperatures increase this species may expand its range to those regions. It may also mean that if lower latitudes become drier *L. chinensis* could decrease in those areas. In contrast *S. grandis* could increase in those areas that become drier, both north and south, as it ranks as the more competitive species. *A. cristatum* was a less dominant species than the other main species measured but there was a suggestion that SDR_2 was marginally greater at higher latitudes. The data suggests it may suffer from competition from the other species at those latitudes if they expand their range under warmer and, or drier conditions. Depending upon the changes in thermal environments, an increase in the C4 grass *C. squarrosa* in the north is also likely. The SDR_2 values for *S. grandis* were greater than for the other grasses indicating it was often better able to utilise current resources than the other species. *S. grandis* is well known to dominate under drier conditions, suggesting that soil moisture conditions were affecting species distribution as much as the thermal gradient.

Latitude effects on N and P nutrients of plant and soil

The study of Koerselman and Meuleman (1996) found that in general, a plant N:P<14 means that N was limiting, whereas N:P>16 indicates P limitation. In this study, the N:P ratio of *S. grandis* was on average higher than 14, whereas the N:P ratios of *L. chinensis* and *C. squarrosa* were often lower than 14 (Fig. 5). The physiological reasons for this are unclear as it may mean that *S. grandis* was more efficient at extracting N from soils than P, whereas the other species may show the reverse. A further possibility is that *S. grandis* may retain more N in plant tissues. Given the demonstrated competitive advantage of

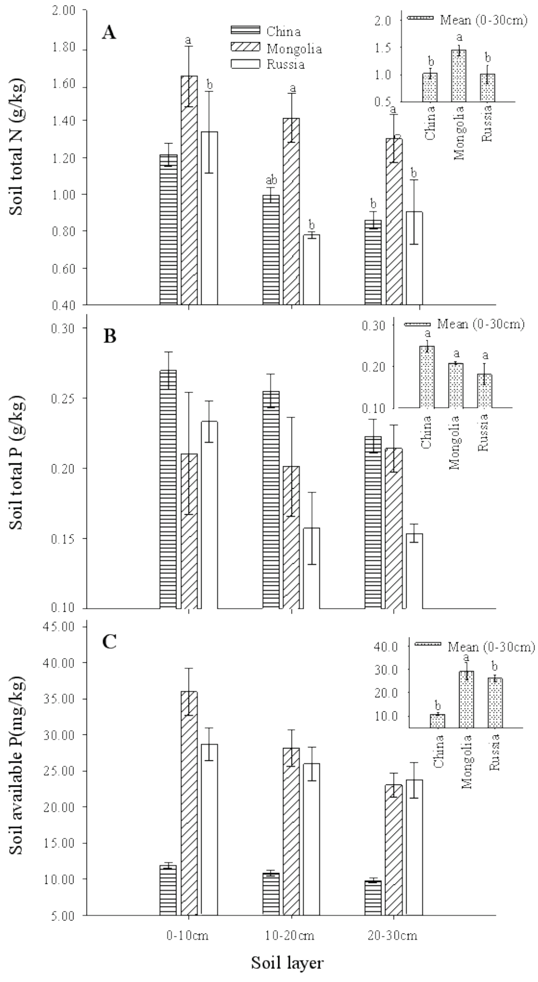

Figure 6. The mean total soil N, P and available P contents for different soil layers in China, Mongolia and Russia

S. grandis in these grasslands (Fig. 3) it is possible that it does extract more N from soils than the other species, particularly under drier conditions. That has implications for the future, especially in Mongolia where soil N levels are higher. A consequence could be greater grassland productivity could be expected, though eventually soil N could be reduced if there is a high rate of utilisation by livestock. Additionally, *S. grandis* may be more limited by phosphorus, while *L. chinensis* and *C. squarrosa* may be more limited by nitrogen.

Our study showed that the N:P ratio of the community and dominant species significantly decreased with increasing latitude in EEST ($P<0.001$). It indicated that the community and dominant plants in the south are possibly more limited by phosphorus, whereas plants in the north could be more limited by nitrogen. The decreasing N:P ratio in the plant and community along the transect does not support the hypothesis that the plant N:P ratio increases with decreasing temperature (Reich and Oleksyn 2004). We suggest that human activities especially grazing utilisation, might be a factor affecting plant N:P and growth status. The finding that the soil AP was lower in Inner Mongolia than in Mongolia and Russia, but there were no significant soil total P differences between Inner Mongolia of China, Mongolia and Russia might mean that the status of bio-geography along the transect was consistent but human activities are more intense in Inner Mongolia than in Mongolia and Russia. In addition, in high latitude (*e.g.* no *Leymus* growth in Russia), a decreasing of N:P ratio for *Stipa grandis* and *Cleistogenes squarrosa* lead to the reducing the N:P ratio (Wright *et al.* 2011). The finding that the N:P ratio of grassland plants was higher in China (Fig. 5) was consistent with other work (Han *et al.* 2005; He *et al.* 2008), but did not support the conclusion of Han *et al*. that the low soil P content led to the low community P content and high N:P ratio in China (Han *et al.* 2005). A significant positive correlation was found between community P content and soil AP content. The approximately 2.5mg/kg increase in AP at higher latitudes compared to the lowest latitudes could suggest that mineral processes in the soil are producing more available N and P, faster than plants can take them up. Our results further support the view that soil AP content would play a vital role in regulating plant N:P ratio. Future work needs to clarify the mechanisms and management practices that influence soil N and AP contents to better judge how climate change will influence these characteristics. It is vital that steppe protection, restoration, sustainable use and management among these countries be enhanced. The N:P ratio of plants on average, declined with latitude (Fig. 5A); this was significant for *S. grandis* and marginally significant for *C. squarrosa* where most samples showed this trend. There was no significant trend for *L. chinensis* but in this case it was not found at latitudes >48°N.

Conclusions

Temperature changes along this extensive N-S transect do influence plant species, the plant community and soil. Soil water conditions were deemed reasonably consistent and of less consequence for the changes identified. The plant community diversity index, above-ground biomass, plant

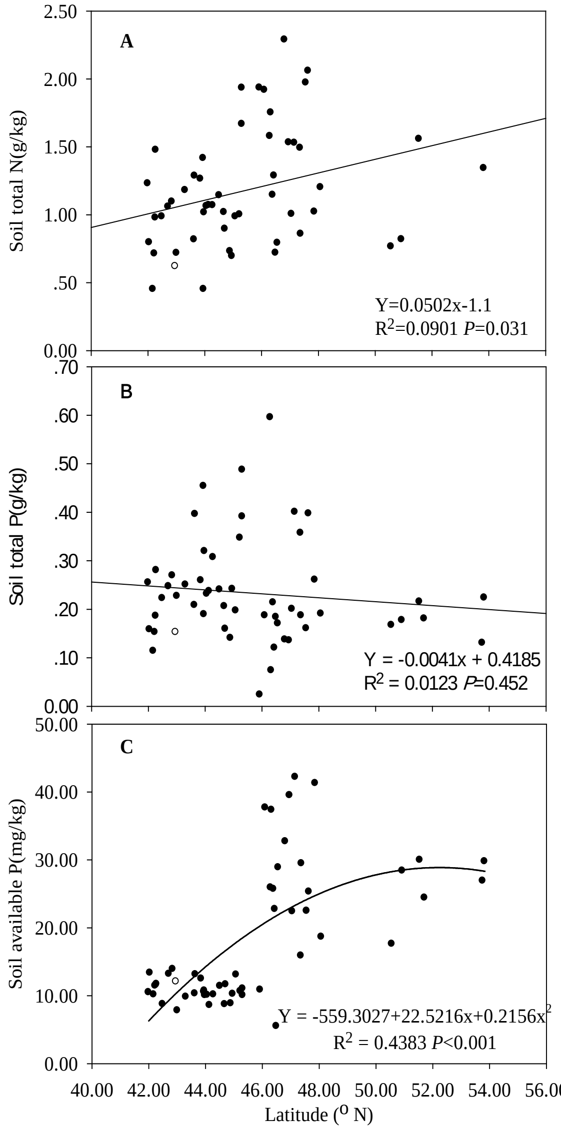

Figure 7. Changes in total soil N, P and available P with latitude in EEST

N:P were found to increase with the increase in temperature (decreasing latitude), whereas the soil N and AP decreased with the increasing of temperature and decrease of latitude. The AP content was Inner Mongolia < Mongolia < Russia. These findings provide the basis for further knowledge of the change and driving force of Eurasian temperate grassland ecosystem as well as helping identify management countermeasures.

Acknowledgement

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