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EDITORIAL

Steppe ecosystems and climate and land-use changes—vulnerability, feedbacks and possibilities for adaptation

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In temperate zones, grasslands such as steppe cover approximately 20% (~10^7 km^2) of the land surfaces and are widely used as pasture (Graetz 1994). Grassland soils are one of the most significant stocks for organic carbon. The degradation of grasslands due to changes in management, intensification of rangeland use or climate changes may significantly affect biosphere-atmosphere exchange for carbon and nitrogen due to the volatilization and dislocation by erosion of huge amounts of C and N previously stored in the soil (White et al. 2000, Schlesinger et al. 1990, Ojima et al. 1993). This is in turn associated with soil fertility decline and reduced productivity.

In the recent past temperate grassland research was largely dominated by work carried out in North America (Schlesinger et al. 1990, Goodrich et al. 1994, Hernandez et al. 2000, Frank and Dugas 2001). However, due to the increasing extent of degradation and desertification of grasslands e.g. in China, public awareness on the vulnerability of grassland ecosystems to changes in rangeland management or climate has risen. This was accompanied by an increasing number of research activities on grassland degradation in several regions worldwide with a strong regional focus on grasslands in China and Mongolia.

Most of the contributions summarized in this special issue are reporting on results as obtained from the Sino-German Research Group MAGIM "Matter Fluxes in Grassland Ecosystems of Inner Mongolia". The MAGIM project, funded by the German Science Foundation (Deutsche Forschungsgemeinschaft, DFG, Research Group 536) with additional support being given by the National Science Foundation of China (NSFC), brought together an interdisciplinary team of scientists from Germany and China with specific expertises in soil science, plant ecology and animal production, micro-meteorology, and biogeochemistry. The regional focus of the project was on steppe systems in the Xilin river catchment of Inner Mongolia (Fig. 1), with Inner Mongolia—besides Tibet—being the most important province in China for grassland based

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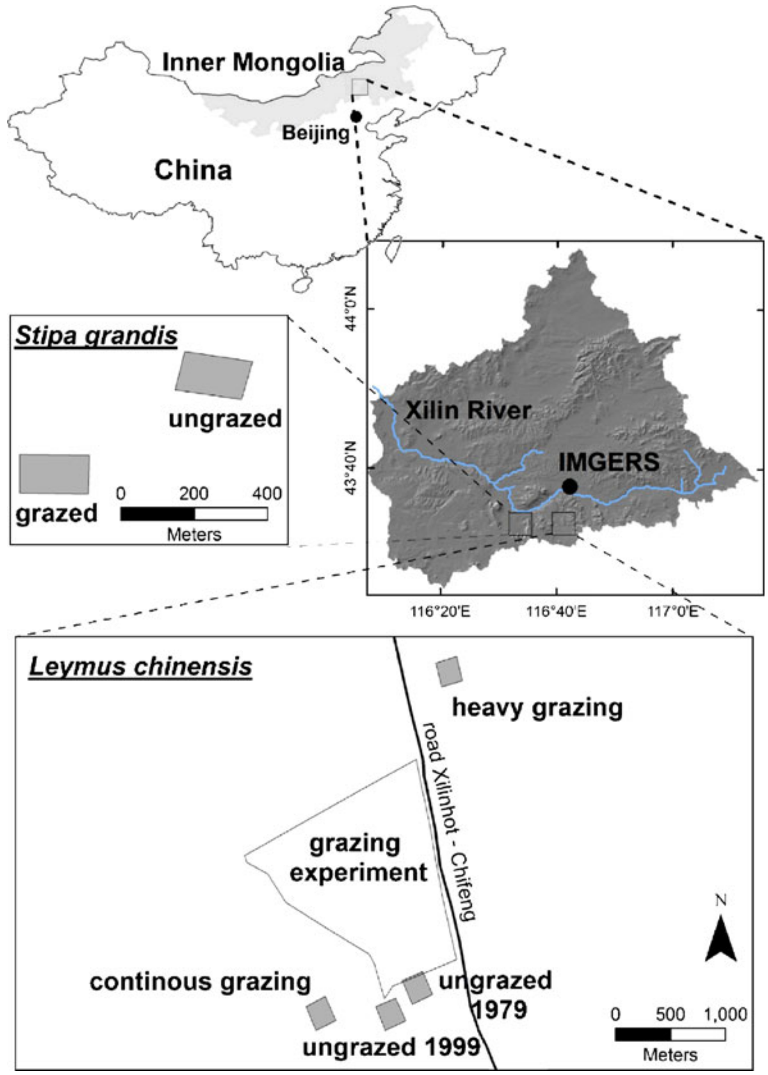

Fig. 1 The maps show the location of the Xilin river catchment in Inner Mongolia, China, the location of the Inner Mongolia Grassland Ecosystem Research Station (IMGERS) and the experimental sites where most of the studies of this special issue have been carried out (author: F.K. Barthold)

animal husbandry. The Research Group major objectives were to analyzing effects of grazing intensity and an improved grazing system—annual alteration of separated grazing and hay making areas instead of a distinct separation of both areas as traditionally favored by the farmers—on grassland productivity, plant species diversity, soil conditions and nutrient fluxes including biosphere-atmosphere exchange processes. Thus, the research contributes to the development, approval and application of indicator systems for assessing ecological effects of grazing pressure on grasslands in semi-arid climate regions and to the provision of guidelines for a future sustainable use of semi-arid grasslands.

Due to changes in climatic conditions, in particular, declining precipitation, the productivity of grasslands in Inner Mongolia gradually decreases from the E to W (Yu et al. 2006) and desertification due to overgrazing is a major problem in large areas. The increasing extent of degradation and desertification of grasslands in Inner Mongolia was strongly influenced by political decisions. In the 1950's and 1960's local farmers were forced to give up their nomadic way of life and to settle in small villages, hamlets or individual farms (Sneath 1998). Together with a moderate increase in number of livestock this policy has increased grazing pressure around the newly established settlements and brought the large scale pastoral movements between seasonal pastures to an end. The new economic policy established in the 1980's, which allowed individuals to profit directly from increased meat or wool production, sharply fostered the pressure on the land resources and resulted in intensified land-use and large scale overgrazing (Jian and Meurer 2001; Graetz 1994; Fig. 2). E.g. Tong et al. (2004) showed that the total area of degraded steppe in the Xilin river basin, Inner Mongolia, China, increased from approximately 7,200 km^2 in 1985 to approximately 7,700 km^2 (72% of the total basin) in 1999. In large parts of Inner Mongolia overgrazing has already led to severe losses of soil organic matter, depletion of nutrients (Steffens et al. 2008; Su et al. 2006) and a decrease in steppe primary productivity (White et al. 2000).

Most of the summarized studies in this special issue have been carried out on experimental sites of the Inner Mongolia Grassland Ecosystem Research Station (IMGERS) (Fig. 1), a research platform being part of the Chinese Ecosystem Research Network (CERN) and belonging to the Institute of Botany, Chinese Academy of Sciences, in Beijing. IMGERS is situated in the center of the Xilin river catchment, with *Leymus chinensis* or *Stippa grandis* steppe (Bai et al. 2004) being the most common land cover type (85% of the area, Yao et al. 2010). In the Xilin region phaeozems (51%), chernozems (15%) and gleysoils (14%) as well as arenosols (16%) in sand dune areas are the dominant soil types (Barthold et al., unpublished). A first detailed study in the region was done by Wiesmeier et al. (2011, this issue) using an innovative digital soil mapping approach to model the spatial distribution of stocks of soil organic carbon, total carbon, total nitrogen and total sulphur for the Xilin river region. The experimental sites encompassed steppe treatment sites where grazing was abandoned since 1979 or later, or where grazing with different intensities were carried out. This experimental approach provided the opportunity to identify grazing effects on a series of ecosystem processes, functions or potential indicators such as stable isotopic composition of ecosystem components (Wittmer et al., 2011, this issue). It is clear from the studies that grazing has a detrimental effect on steppe topsoil properties. Summarizing and integrating current knowledge and recent experimental findings Kölbl et al. (2011, this issue) show that intensive grazing clearly decreased soil aggregation and the amount of fresh, litter-like particulate organic matter. As a consequence of weak aggregation in combination with animal trampling, soil organic matter mineralization is enhanced, whereas topsoil bulk densities were increased and infiltration rates, saturated hydraulic and air conductivities (Reszkowka et al., 2011, this issue) were found to be decreased. The effects of soil structure disruption due to grazing was further amplified by the degradation of vegetation patches and resulted in a texture controlled wettability of the soil surface (Kölbl et al., 2011, this issue). These grazing induced changes within the study area accelerated the influence of soil and vegetation parameters on soil moisture (Schneider et al., 2011, this issue) and lowered soil water storage and plant available water during all seasons (Zhao et al., 2011, this issue).

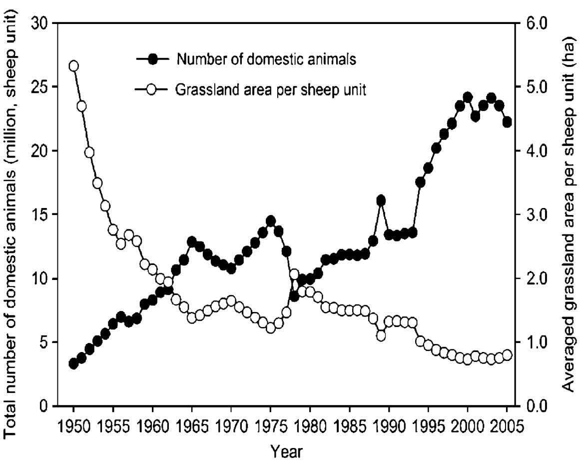

Fig. 2 Changes in livestock numbers in Xilin river catchment region, Inner Mongolia, from 1950–2005. Census data of the Xilinhot county administration, Inner Mongolia, with the Xilinhot county covering most parts of the Xilin river catchment

Degradation in topsoil properties partially explains why aboveground net primary production (ANPP) was negatively affected by grazing intensity (Schönbach et al., 2011, this issue) or why the soil microbial biomass, activity and protozoan abundance was lower at grazed sites as compared to ungrazed sites (Qi et al., 2011, this issue). On the other hand, Wu et al. (2011, this issue) showed that the effect of grazing on gross N mineralization was non-uniform. At low stocking rates gross N mineralization tended to decrease but increased with higher grazing pressure. Grazing decreased recovery of applied ^{15}N both in plant and microbial N pools but strongly promoted NO_3^- accumulation in the soil and, thus, negatively affected potential ecosystem N retention. This appeared to be closely related to the grazing-induced decline in easily degradable soil C availability at increased stocking rate (Wu et al. 2011, this issue).

Grazing also affected plant functional traits. This was shown in a study dealing with two dominant steppe species, namely *Leymus chinensis*, a C3 perennial rhizome grass, and *Cleistogenes squarrosa*, a C4 perennial bunchgrass (Zheng et al. 2011, this issue). The results obtained at sites of the grazing experiment of MAGIM show that *C. squarrosa* is more resistant to grazing, specifically under heavy grazing pressure and in years with below average annual rainfall.

Besides being affected by grazing, ANPP as well as soil ammonium and nitrate availability in the investigated steppe ecosystems (Giese et al. 2011, this issue) was largely dependent on annual rainfall amounts, with the long-term average annual rainfall at the IMGERS station being 330 mm (Bai et al. 2004). Based on site scale spectral reflectance measurements at differently grazed sites (Fan et al. 2011, this issue; 2008) remote sensing data were used by Schaffrath et al. (2011, this issue) to demonstrate the pronounced effect of interannual rainfall variability on the average leaf area index in the Xilin catchment, with values clearly lower (LAI=0.52) in dry as compared to wet (LAI=0.72) years. Furthermore, ANPP may be severely restricted by nutrient availability even under ambient precipitation levels (Ronnenberg and Wesche 2011, this issue), whereas belowground net primary productivity may decline with increased availability of water or nitrogen (Li et al. 2011, this issue). The fact that ANPP of the investigated steppe systems is nutrient limited could be further confirmed by the observed plant N:P ratios, which indicate a relative limitation of plant production by N or P in the investigated semiarid grasslands under sufficient water supply (Gong et al. 2011a, this issue).

The provided research results show that the investigated steppe ecosystems are extremely sensitive to increases in livestock stocking rates in terms of changes in soil properties and plant production. This should be considered for the development of management strategies to protect these fragile ecosystems from degradation. Liu et al. (2011, this issue) concluded from their observation that plant community ANPP recovered more quickly at sites with low to moderate grazing intensities as compared to heavily grazed sites. They show that periodic grazing cessation may possibly be a management option to sustain long-time productivity. The study of Schönbach et al. (2011, this issue) and Wan et al. (2011, this issue) shows that annual alteration of separated grazing and hay making areas can increase the resilience of the investigated steppe ecosystems with regard to plant biomass production, thereby avoiding sheep-grazing induced plant species shifts. It should also be discussed if low dose fertilization of steppe is a possible means to increase plant production, since e.g. the study of Gong et al. (2011a, b, this issue), Ronnenberg and Wesche (2011, this issue) and Fanselow et al. (2011, this issue) showed that plant nutrient limitation and plant re-growth following grazing can be alleviated by N fertilization. However, it should also be considered that N fertilization may lead to a decline in species richness and an increase of ANPP of grasses on costs of forbs (Liu, 2011, this issue).

Besides the need to further explore management options for sustainable livestock management in Inner

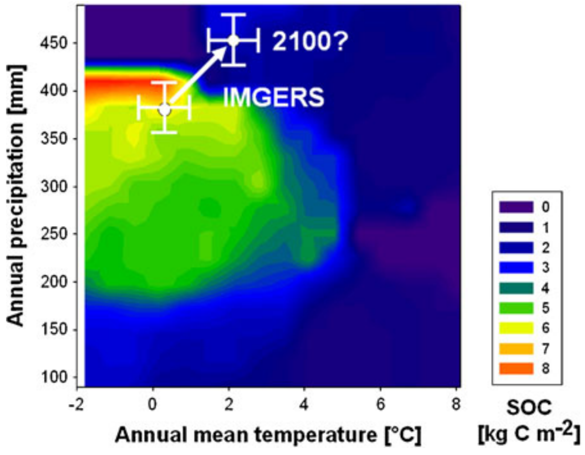

Fig. 3 Soil organic C storage in ungrazed steppe soils (0–0.3 m) in dependency of annual mean values of precipitation and temperature. Integration of data was done based on a survey on soil C storage in ungrazed steppe soils (*N*=26) by Ojima et al. (1999). The cross shows actual soil organic C storage (±uncertainty) at the ungrazed IMGERS research sites and its possible change under conditions of predicted climate change

Mongolia one needs to be aware that these fragile ecosystems are further threatened by climate change. The capacity of grassland soils to store huge quantities of C and N is a function of climate and land management. Grazing affects the heterogeneity of plant communities (Burke et al. 1998; Evans et al. 2001; Vinton and Burke 1997; Schneider et al. 2011, this issue; Zheng et al. 2011, this issue) and reduces above and belowground productivity. However, the importance of climate for soil C and N storage may override management effects in the future. For steppe soils in China and Mongolia there are indications that C storage is highest when annual rainfall ranges from 350 to 420 mm and mean annual temperature is <1°C (see Fig. 3) (Parton et al. 1995; Christensen et al. 2004). Prognoses from modelling studies indicate that the change of temperature and precipitation related to climate change will lead to a loss of carbon stock and aboveground net primary productivity in Inner Mongolian steppe ecosystems (Xiao et al. 1995). However, this still remains highly uncertain. Figure 3 indicates that e.g. in the Xilin river catchment soil C and N storage might be close to the optimum, i.e. that any change in climate, either increase in temperature or changes in precipitation will lead to a reduction of soil C and N storage. However, up to now the temporal timescale of likely changes in soil C and storage due to changes in climate remains unclear and an interaction with steppe management has so far not been investigated. In view of the importance of steppe ecosystems for regional and global C balances and as sources and sinks for greenhouse gases (Wolf et al. 2010; Chen et al. 2011 this issue) and in view of the vulnerability of these systems to global changes it is obvious that they deserve further research attention.

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