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Carbon modeling and emergy evaluation of grassland management schemes in Inner Mongolia

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ABSTRACT

There is relatively little research on how management affects carbon storage and the carbon cycle in grasslands of China, and how this in turn affects regional development and natural capital conservation. Inner Mongolia has 25% of the total grassland area of China and about 60 million livestock. Productivity of the traditional grazing schemes in this area is very low; in addition frequent natural disasters greatly affect livestock production. The grasslands of northern China form a very important eco-economic community belt, thus we ask, “What is the future of this region and what will be its role in the carbon cycle under development pressure and the new conditions caused by climate change?” Using the emergy synthesis method, carbon models are constructed of the natural grasslands under different animal grazing pressures and increased atmospheric carbon dioxide concentrations and the ecological–economic benefits of several different grassland utilization schemes are compared using emergy evaluation. The result shows that in grazing scheme total C emission will be 4087 kg/ha in one hundred years which supports the conclusion that over the long run grasslands can be a carbon source due to overgrazing. We estimate that the natural capital of these grasslands is around 13,303 em$/ha and that is provides 106 em$/ha/yr in ecosystem services. If 90% of the natural grassland can be reserved by using small-scale intensive grazing systems, we estimated these natural grasslands can provide 7.6 billion em$/yr of ecosystem services and preserve 955 billion em$ in natural capital, which is helpful information for proper policy making and in establishing a scientific strategy for sustainable development of the grasslands in north China, not only from the perspective of the indigenous nomadic culture, but also from an economic–ecological perspective.

1. Introduction

As indispensable natural capital, grasslands play a very important role in moderating the biospheric feedbacks of atmospheric CO_2 increase and climate changes (McGilloway, 2006). China’s grasslands contain 9–16% of the total carbon in world grasslands, although they only comprise 6–8% of the total world grassland area (Ni, 2002). At the same time they make large contribution to the world carbon storage and may have significant effects on the carbon cycle, but there is relatively little research on carbon storage and the carbon cycle in the grasslands of China (Fang et al., 1996; Feng et al., 2001; Ni, 2002). Some studies only focused on estimating the carbon storage in grasslands at the national level (Fang et al., 1996; Ni, 2002). Due to lack of information on the below-ground biomass component of Chinese grasslands, which was estimated only by multiplying by the ratio of above to below-ground biomass from the literature, the carbon of grasslands as estimated cannot be completely accurate (Fang et al., 1996). Human activities in the last two decades have had important impacts on Chinese grasslands, which may have already altered the total carbon stock in grasslands. Inner Mongolia has 25% of the total grassland area of China and about 60,000,000 livestock (Ni, 2002). Grassland productivity of the traditional grazing mode in this area is only 1/27 that of American grasslands (Dong and Zhang, 2005). Dong and Zhang (2005) calculated the direct and indirect loss of grassland-stockbreeding caused by degeneration according to the evaluation standards in

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UNEP for economic loss due to desertification (Lu and Wu, 2002). He found that 5.68 billion Yuan (CNY) were lost every year, which was 1.3 times the production value of grassland-stockbreeding over the last 50 years. Inner Mongolia's grasslands are the environmental buffer for Beijing and the northern part of China and they are an important foundation for agricultural economic development. These grasslands connect Mongolia and Russia and cover 86 million ha containing five different kinds of grasslands that play a large role in reducing CO_2 emissions and controlling wind erosion (Dong and Zhang, 2005). Approximately 79.78 million ha of this area (about 93%) are potentially utilizable for grazing (Dong and Zhang, 2005). Many investigating sustainable use of grasslands try to find an optimal grazing scheme that can support the increasing requirement for feed and not damage the environment. The question is, "Is there some possible future where the natural grassland plays an important role in animal production and at the same time does not unsustainably deplete natural capital and associated ecosystem services?" There has been much debate on this question, since sand storms have begun to occur more and more frequently over the last 20 years. As carbon pool is a critical but understudied component of natural capital in Chinese grasslands, it is important to evaluate from both an ecological and economic perspective how it can be preserved in the midst of the increased demand for animal production. This paper models carbon emissions and evaluates the ecological economic effects predicted under different grassland management schemes in Inner Mongolia. Based on the results of model simulations, we give suggestions to policy makers to promote the sustainable development of grasslands in this area.

2. Materials and methods

We compare the ecological and economic benefits of increasing animal production on natural grasslands versus animal production on smaller areas of intensive grasslands in Inner Mongolia. Net carbon flux for natural grasslands under natural and managed animal production schemes is estimated using simulation models. The results of the carbon flux model for natural grasslands were used in the emergy evaluation to compare the managed natural grasslands with the intensive grassland using indices derived from emergy. The management schemes, carbon flux simulation modeling technique, and emergy evaluation are described in the following three sections.

2.1. Grassland management schemes

We evaluate three management schemes for grassland: (1) natural grassland free from grazing, (2) natural grassland with grazing, and (3) intensive pasture with grazing. Data for both the natural and intensive grassland come from long-term study sites, which are described below. Animal stocking density for schemes (2) and (3) are described thereafter.

The study site of the natural grassland is situated in the southern part of the Xilin river basin, Inner Mongolia, China, approximately 1265 m above sea level. The climate is temperate and semi-arid with a mean annual rainfall and temperature of 350 mm and 0.3 °C. Soil organic C content 1.37–1.53% in the upper 20 cm. All the data for the natural grassland come from the *Leymus chinensis* permanent plot (43°32′58″N and 116°40′34″E) of the Inner Mongolian Grassland Ecosystem Research Station where the vegetation consists of 70 species, and the principal grasses are *L. chinensis*, *Stipa grandis*, *Agropyron cristatum*, and *Cleistogenes squarrosa*. The plot has been free from grazing since it was fenced in 1979, therefore, a mature and steady-state system could be assumed for the community (Li et al., 2002). The intensive pasture is located in the Wengniute Banner of Chifeng City in Inner Mongolia. The climate is warm and semi-humid with a mean annual rainfall 350–450 mm and cumulative temperature of above 10 °C is 2800–3100 °C over the year, which is suitable for planting *alfalfa* with high production. Data for the intensive grassland come from Dong et al. (2007).

Table 1
Annual carbon input–output in the *Leymus chinensis* community (Li et al., 2002).

	Fluxes	Carbon weight ($g\,C\,m^{-2}\,a^{-1}$)
Input	Shoots	79.8
	Roots	311.9
	Summed	391.7
Output	Net soil respiration	346.9
	Consumed by insects	14.7
	Standing-dead loss	3.2
	Summed	364.8
Balance		26.9

Grazing is the main land use practice of grasslands in China, and most grasslands have been grazed from several decades to hundreds of years. We estimated grazing effect from sheep production on the carbon budget of natural grasslands assuming a stocking density equivalent to the natural wild animal density on these grasslands of 150 kg/ha or 3 heads sheep unit/ha.[1] We also evaluate doubling and tripling of this stocking density for the natural grassland, to determine the potential economic and ecological effects of attempts to increase sheep production in this system. In these scenarios, it should be noted that *grazing pressure* (animal consumption/plant production) is more than doubled or tripled because inputs are held constant and grass production decreases as a result of decreased light interception.

2.2. Natural grassland carbon flux model

Sufficient data on the long-term effect of grazing pressure on the net carbon flux of Inner Mongolian grasslands does not exist; we therefore modeled these effects. Carbon in the grassland can be traced through the ecosystem in a cycle. Carbon cycles from the atmosphere to plants (photosynthesis), from plants into insects and animals (incorporation into biomass), from plants insects and animals into microbial biomass and soil organic matter (decomposition), from all living organisms directly into the atmosphere (respiration) and also out of the system via export (erosion). According to this cycle, we model the carbon flow in the grassland between these components.

General biogeochemical models hardly reflect dynamic properties of systems and they do not describe the succession of ecosystems especially when models are to be used to make predictions (Zhang et al., 2010). The carbon model of natural grassland was designed using the systems modeling language described by Odum (2000). The model was calibrated from data from the Li et al. (2002) study summarized in Table 1. Modeling with energy systems language is a methodology for converting static systems diagrams representing a network of flows, storages and process interactions into models based on their mathematical, energetic, cybernetic and hierarchical relationships. A full explanation and application to many fields and scales was provided in book form Odum and Odum (2000). A benefit for using this modeling technique here is that the same model structure can be used as a basis for natural capital and ecosystem service valuation using emergy synthesis. We model the carbon budget of the natural grassland

[1] In China , a sheep unit usually is an indication of stocking density. One sheep unit is described as an ewe with 50 kg weight and consumption of 1.8 kg hay one day and can nurse half year old lamb (China industrial standards on agriculture NY/T 635-2002).