Ecological Indicators 91 (2018) 555–561

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Original Articles

Temporospatial patterns of human appropriation of net primary production in Central Asia grasslands

Xiaotao Huang[a,b], Geping Luo[a,b,*], Qifei Han[c]

[a] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Nanjing University of Information Science & Technology, Nanjing 210044, Jiangsu, China

ARTICLE INFO

Keywords:
HANPP
Temporospatial patterns
D_r
Model
Grazing

ABSTRACT

Quantifying and mapping grassland human appropriation of net primary production (HANPP) is vital for the sustainable use of grasslands. However, grazing process was not effectively considered in previous studies, leading to biased results. Although grasslands are widespread in Central Asia, temporospatial patterns of HANPP in Central Asia grasslands are still unclear. In this study, to effectively consider grazing process, we used the Biome-Biogeochemical Cycles grazing model to estimate HANPP and explore its temporospatial patterns in Central Asia grasslands from 1979 to 2012. In our study, net primary production includes aboveground and belowground components. Our estimates showed that HANPP was 47 g C/m^2/yr, which represented 34% of Central Asia grassland potential net primary production (NPP_{pot}) and HANPP efficiency was 70% in this region. Interannual variations in HANPP and HANPP as a percentage of NPP_{pot} (HANPP%NPP_{pot}) were significantly positively related to grazing intensity ($P < 0.01$). Interannual variation in HANPP efficiency was negatively related to grazing intensity ($P < 0.1$). HANPP showed strong regional variation. High HANPP values were mainly observed in temperate grassland and some forest meadow. Low HANPP values were mainly observed in desert grassland and some forest meadow. The spatial pattern of HANPP%NPP_{pot} was similar to that of HANPP in this region. Interannual variations in HANPP were mainly determined by population change and economic development. Spatial patterns of HANPP were primarily determined by grazing intensity and grazing system. This study contributes to a better understanding of the temporospatial patterns of HANPP in Central Asia grasslands and provides data to support the rational use of grassland resources.

1. Introduction

Human appropriation of net primary production (HANPP) is the difference between potential net primary production (NPP_{pot}) and actual net primary production (NPP_{act}) remaining in the ecosystem after harvest (Haberl et al., 2007; Ma et al., 2012). It derives from consumption of terrestrial photosynthesis products, as well as the loss of biomass caused by changes in human land use (Haberl et al., 2007; Ma et al., 2012). It represents the degree to which human society influences natural ecological systems and is based on the knowledge that the material and energy required for human survival and development is dependent on the net primary production (NPP) (Rojstaczer et al., 2002; Vitousek et al., 1986). NPP is the net amount of carbon assimilated in a given period by vegetation and determines the amount of energy available for transfer from plants to other trophic levels (Artacho and Bonomelli, 2017; Chen et al., 2017; Deng et al., 2017). HANPP not only reduces the food sources available to other species, but it also distinctly alters the material and energy flow in biogeochemical cycles (BGC) and within food webs (Haberl et al., 2005, 2004a). Quantifying HANPP is important for ecological assessment of regional sustainable development. Furthermore, HANPP estimation has received considerable attention in the international community and has become a major method for ecological assessment (Krausmann et al., 2013, 2012).

Grasslands are widespread in Central Asia and serve important economic and ecological functions, such as material production, climate regulation, soil and water conservation, sand stabilization, soil improvement, and biodiversity preservation (Eichelmann et al., 2016;

Abbreviations: BGC, biogeochemical cycles; HANPP, human appropriation of net primary production; HANPP%NPP_{pot}, human appropriation of net primary production as a percentage of potential net primary production; KAZ, Kazakhstan; KYR, Kyrgyzstan; NPP_{act}, actual net primary production; NPP_{pot}, potential net primary production; TJK, Tajikistan; TKM, Turkmenistan; UZB, Uzbekistan

* Corresponding author at: State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, Xinjiang, China.

E-mail address: luogp@ms.xjb.ac.cn (G. Luo).

https://doi.org/10.1016/j.ecolind.2018.04.045
Received 2 December 2017; Received in revised form 15 April 2018; Accepted 17 April 2018

Huang et al., 2017; Zhang et al., 2016). Due to lack of water resources, grassland ecosystems are considered highly sensitive and vulnerable to human disturbance and climatic change in this region (Han et al., 2016; Zhang et al., 2012). These grassland resources are commonly used for grazing (Han et al., 2016; Zhang et al., 2012). The vast rangelands of Central Asia form the world's largest contiguous area of grazed land (Freitag and Wucherer, 2005; Han et al., 2016). Quantifying HANPP can help us to further assess grazing effects on grassland ecosystems in terms of carbon cycling, ecosystem services, and sustainability (Haberl et al., 2012, 2004b; Rojstaczer et al., 2002). However, the current studies in this region lack sufficient detail to provide adequate knowledge in this field. Thus, we do not have a clear understanding of the temporospatial patterns of HANPP in this region, which is detrimental to promoting rational use of Central Asia's grassland resources.

Previous studies mainly combined models with statistical data to estimate HANPP in grazed land. However, the grazing process was not effectively considered, leading to biased results (Haberl et al., 2007; Krausmann et al., 2013, 2012). Luo et al. (2012) developed the Biome-BGC grazing model by integrating a defoliation formulation (Seligman et al., 1992) into the Biome-BGC model, producing a grazing model for describing the effects of grazing on the carbon cycle of grassland ecosystems. The Biome-BGC grazing model is a process-based model that effectively estimates NPP_{pot}, NPP_{act}, and the carbon consumed by animals (Han et al., 2016; Luo et al., 2012). Therefore, HANPP can be estimated in Central Asia grasslands using this model.

In this study, based on the Biome-BGC grazing model, HANPP was estimated in Central Asia grasslands from 1979 to 2012. The primary objectives of this study were to investigate interannual variation in grassland HANPP from 1979 to 2012 and to explore spatial patterns of grassland HANPP in Central Asia. In our study, NPP includes aboveground and belowground components.

2. Materials and methods

2.1. Study area

Central Asia, with widespread grasslands, occupies nearly 5.7×10^6 km^2 and includes five republic countries [Kazakhstan (KAZ), Kyrgyzstan (KYR), Tajikistan (TJK), Turkmenistan (TKM), and Uzbekistan (UZB)] and Xinjiang in China (Fig. 1a) (Cowan, 2007). Because Central Asia is in the Eurasian hinterland and far from ocean, it has the typical continental arid climate characteristics. Average annual precipitation is less than 300 mm, however, significant spatial differences in precipitation exist. For example, annual precipitation in the desert is less than 100 mm, or even less than 50 mm, while that in the mountains is more than 500 mm, and even up to 1000 mm (Buslov et al., 2007). Three grassland types occur depending on terrain and climate: forest meadow, temperature grassland, and desert grassland. Grassland above 1650 m a.s.l. is forest meadow. Grassland below 1650 m a.s.l. is either temperate or desert grassland, depending on the climate. Temperate grassland occurs where plant growth is more restricted by temperature than by precipitation, while desert grassland occurs where plant growth is more restricted by precipitation than by temperature (Fig. 1a). Due to its unique geography and natural conditions, the Central Asia grassland ecosystem is very fragile. Furthermore, the vast rangelands of Central Asia form the world's largest contiguous area of grazed land. Grazing is the main human disturbance on grasslands in this region. Forest meadow is dominated by seasonal pasture. Desert grassland is dominated by seasonal pasture and rotational grazing, and temperate grassland is dominated by annual pasture (Han et al., 2016; Zhang et al., 2012). Overgrazing (i.e., pronounced decrease in NPP caused by grazing) is serious in some parts of Central Asia, and is not sustainable utilization of grasslands (Fig. 1b).

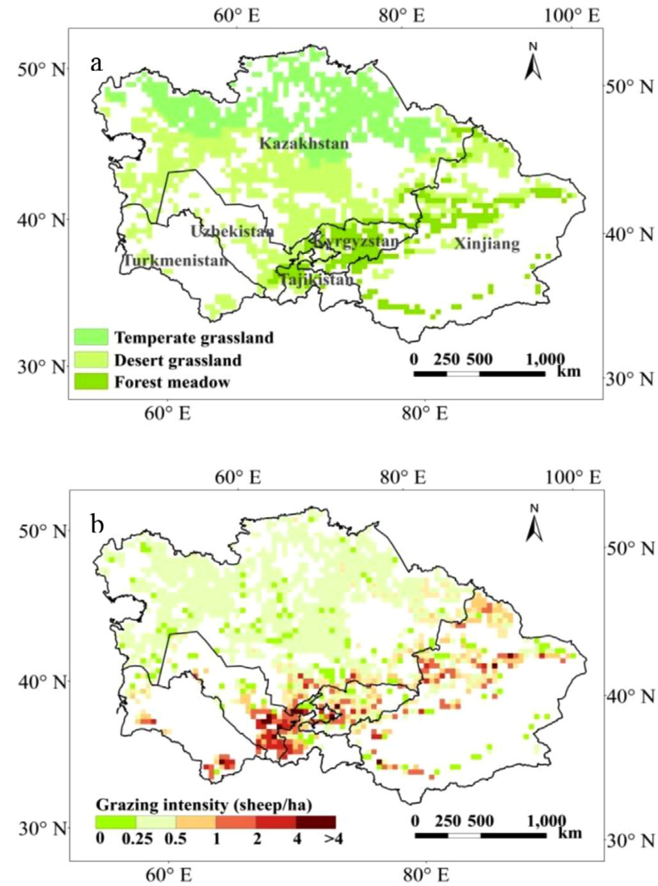

Fig. 1. Distribution of grassland types (a) and grazing intensity (b) in Central Asia from 1979 to 2012.

2.2. Methods

We used the estimating method of HANPP in grazed lands per Haberl et al. (2007). Grazing is the most important human disturbance on grasslands in Central Asia. Compared with grazing, disturbance from other human activities is very limited in this region (Han et al., 2016; Zhang et al., 2012). In addition, the effects of other human activities are very difficult to estimate because much of the necessary data are unavailable. Therefore, grazing can be considered the only human disturbance when HANPP is estimated in Central Asia grasslands.

The Biome-BGC grazing model is a process-based ecosystem model that can effectively simulate the fluxes and storage of carbon, both in grazed and ungrazed grasslands over large areas (Han et al., 2016, 2014). In the model, NPP is estimated as (Luo et al., 2012)

$$NPP = C'_{veg} + C_{litter} + D_r \tag{1}$$

where C'_{veg} is vegetative carbon, C_{litter} is litter carbon, and D_r (g C/(ha·d)) is the carbon consumed by animals (NPP harvest) (Seligman et al., 1992), and

$$D_r = G_e S_r (C_{leaf} - (C_{leaf})_U)(0 < D_r < S_r D_x) \tag{2}$$

where G_e is the grazing efficiency of the livestock (ha/d per sheep unit), S_r is the grazing intensity (sheep/ha), C_{leaf} is the C in the leaf biomass (g C/m^2), $(C_{leaf})_U$ is the residual aboveground C_{leaf} that is unavailable to livestock (g C/m^2), and D_x is the consumption rate of the livestock based on satiation (g C/(d·sheep)). In accordance with Luo et al., (2012), the grazing efficiency of the livestock is 0.011 ha/d per sheep unit, $(C_{leaf})_U$ is 6.75 g C/m^2, and D_x is 2.4 g C/(d·sheep).

In this study, HANPP is calculated as (Haberl, 1997; Haberl et al., 2005, 2004a)