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Quantitative assessment of human-induced impacts on marshes in Northeast China from 2000 to 2011

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ABSTRACT

Distinguishing the relative role of human activities from climatic changes in terms of their impact on wetlands is vital for understanding the consequences of global change and implementing sustainable management strategies for these important ecosystems. As the major type of wetland in Northeast China, marshes offer crucial ecosystem functions and services. This study attempts to analyze the impact of human activities on marshes as well as the spatiotemporal difference of this impact among 10 national nature reserves in Northeast China. These aims are accomplished by examining a relative impact contribution index (RICI) based on the Carnegie Ames Stanford Approach (CASA)-derived potential net primary productivity (PNPP) and actual net primary productivity (ANPP). The results demonstrate that the PNPP and ANPP in the study area had obvious spatial heterogeneity and decreasing trends from 2000 to 2011. The results also reveal that human activities induced productivity loss by a mean value of 10.14% relative to PNPP, 84 $gC\,m^{-2}\,yr^{-1}$. A decreased RICI in Northeast China from 2000 to 2011 indicates reduced human disturbance. A comparison among 10 national nature reserves suggests that the Honghe nature reserve, which had the smallest RICI (6.97%) and change slope value, was subjected to the smallest anthropogenic influences, while the Dalaihu nature reserve experienced the largest human disturbance, with a RICI value of 57.60%. Based on the negative RICI value for all of the nature reserves and the increasing RICI trends for five of the reserves, we conclude that there is a need for more wise management measures to improve marsh protection.

1. Introduction

As important natural ecosystems, wetlands play a significant role in maintaining material circulation, protecting biodiversity, and serving the socioeconomic sustainable development (McLaughlin and Cohen, 2013). Marshes are a type of wetland that are frequently or continually inundated with water, characterized by emergent herbaceous vegetation that is adapted to saturated soil conditions, and often found at the edges of lakes and streams (Keddy, 2010). Marshes provide predominant habitats for many rare, endangered water birds and other animal species worldwide (Desta et al., 2012; Turner et al., 2000).

Concurrent with obvious climatic changes, wetlands, especially marshes, worldwide have experienced serious loss and degradation resulting from anthropogenic impacts (Day et al., 2011; Ozesmi and Bauer, 2002; Rebelo et al., 2009). The net primary productivity (NPP), an effective proxy for characterizing vegetation dynamics and carbon sequestration capacity, of marshes also exhibits obvious variability as a result of significant human activities and climatic changes (Ewe et al., 2006; Yu et al., 2009). Although significant human disturbances affect marshes, less is known regarding the quantitative role in the impact of human activities on marshes.

The potential net primary productivity (PNPP) and actual net primary productivity (ANPP) are effective in distinguishing the effect of human activities from climatic conditions (Haberl et al., 2007; O'Neill and Abson, 2009). The ANPP is the net amount of carbon assimilated in a given period by vegetation under stress due to climatic conditions and human activities, while the PNPP is the

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productivity that hypothetical vegetation would have actual climatic conditions and in the absence of human disturbance (Haberl et al., 2007). The difference between the PNPP and ANPP, defined as the human appropriation of net primary production (HANPP), indicates the human disturbance (O'Neill and Abson, 2009). To quantify the anthropogenic impact, estimating the PNPP is a critical step. Wessels et al. (2007) attempted to evaluate the role of human activities on land degradation, but they estimated the productivity only from rainfall. Grosso et al. (2008) and Grosso and Parton (2010) developed a regression model to estimate the global PNPP from climate and land cover data. Although this regressive model used remote sensing data to account for the spatial heterogeneity of the productivity, the nonlinear relationships between the productivity and rainfall or temperature and the influences of other environmental factors (e.g. solar radiation) were ignored. Therefore, the PNPP resulting from the regressive model was not accurate. Raich et al. (1991) derived a spatially explicit PNPP using the Terrestrial Ecosystem Model (TEM) in order to evaluate human impact on the terrestrial NPP in South America. The TEM considers climate stress and addresses the nonlinear correlation between the PNPP and climatic factors. The Carnegie Ames Stanford Approach (CASA) based on ecosystem processes and light-use efficiency for the PNPP and ANPP was applied to assess the relative role of human activities and climate changes in the sandy desertification of Ordos regions in China (Xu et al., 2009). This CASA application integrated the advantages of remote sensing and the light-use efficiency model to distinguish human-induced impacts from climate factors in land degradation at a regional scale. The CASA and TEM provide a broadly applicable approach to estimate the PNPP and assess the human-induced impact on marshes.

Northeast China has the largest area of marshes in China; these marshes are important for protecting species diversity and regulating the regional climate and hydrology of Northeast Asia (Ma et al., 1993; Zhang et al., 2013). The increased population and rapid economic development in this area have severely affected the marshes of this region (Schuyt, 2005; Song et al., 2012), as indicated by a significant loss of the marsh area, landscape fragmentation and species change (Liu et al., 2013; Wang et al., 2011a, 2011b). Meanwhile, the loss and fragmentation of marshes induced by the expansion of residences, roads, and dams resulted in an obvious decrease in the productivity of marshes (Guo et al., 2008; Zhou et al., 2013). To assess the marsh degradation and explore the potential of various policies for the effective management and protection of marshes (Cardoch et al., 2002; Imhoff et al., 2004), it is necessary to quantify the role of human activities in modifying marshes in Northeast China and to investigate the spatial difference of these effects. Thus far, such a quantitative assessment of the marshes in this region has not been performed.

In this study, the CASA was used to estimate the ANPP and PNPP in order to quantitatively assess the impact of human activities on marshes. The objectives were to 1) describe the pattern and dynamics of the marsh productivity, 2) quantify the impacts of human disturbance on marshes from 2000 to 2011, and 3) investigate the anthropogenic impact on marshes in typical nature reserves.

2. Materials and methods

2.1. Study area

Northeast China covering the Heilongjiang, Jilin, and Liaoning Provinces, as well as the eastern part of the Inner Mongolia Autonomous Region (IMAR) (Hulunbuir, Xingan, Chifeng, and Tongliao cities), extends from 115°32′ E to 135°09′ E and from 38°42′ N to 53°35′ N (Fig. 1). This region is separated from Russia by the Amur, Argun, and Ussuri Rivers; from North Korea by the Yalu and Tumen Rivers; and is adjacent to Mongolia. The study area is surrounded by medium-high and low mountains along three directions, including the Changbai Mountains in the southeast, the Greater Khingan Mountains in the northwest, and the Lesser Khingan Mountains in the northeast. The Songnen, Liaohe, and Sanjiang plains are located in the central and southern parts and in the northeastern corner, respectively; the Hulun Buir plateau is located in the western tip. A large portion of this area is characterized by a temperate monsoon continental climate, except for areas located at >50° N latitude, which are dominated by the cold monsoon. Winter is long and cold, but summer is short. The precipitation varies significantly within a year, with 70–80% of the total precipitation occurring between mid-June and mid-August. The precipitation decreases from 1100 mm in the southeast to 250 mm in the northwest. The apparent differences of this region in terrain and climate determine the vegetation pattern (Mao et al., 2014).

Widely distributed rivers, lakes, and permafrost are important for the existence of marshes in Northeast China. Ten national nature reserves representing the typical marshes were selected to compare human-induced impact on marshes. These reserves are labeled in Fig. 1. These wetland natural reserves contain riverine marsh, lacustrine marsh, and estuarine marsh. The major vegetation types in marshes are *Carex lasiocarpa*, *Carex pseudocuraica*, *Carex meyeriana*, *Calamagrostis angustifolia*, and *Phragmites communis*.

2.2. Data collection

2.2.1. Remote sensing data

The moderate resolution imaging spectroradiometer (MODIS) monthly NDVI datasets from 2000 to 2011 at 1 km resolution were used to drive the CASA. The land surface reflectance of the same period at the same spatial resolution was processed to obtain the monthly land surface water index (LSWI). The MODIS NDVI and reflectance products (MOD13A3) were downloaded from the website https://lpdaac.usgs.gov/products/. Image mosaic and format conversion were accomplished in the MRT software provided by the web site (ftp://e4ftl01u.ecs.nasa.gov/MOLT/). Furthermore, smoothing by the method of logistic curve was conducted on the MODIS NDVI and reflectance products to remove the unrealistic variations in ENVI software. This method was well used for MODIS products by Zhang et al. (2003).

2.2.2. Meteorological data

Meteorological datasets, including the monthly mean temperature, monthly precipitation and daily sunshine hours, were extracted from meteorological records from 2000 to 2011. These meteorological data recorded at 109 meteorological stations in Northeast China were obtained from the China meteorological sharing service center (http://cdc.cma.gov.cn). The daily sunshine hours were converted to monthly solar radiation (SOL) based on the latitudes of the meteorological stations and the adjusted coefficient changing with latitude (Huang et al., 2010; Seaquist et al., 2003). All of the data were interpolated to a raster format at a 1 km spatial resolution and a specified geographic projection (WGS 1984 Albers).

2.2.3. Marsh distribution data

The vegetation type determines the value of maximum light-use efficiency, which is the important input for the CASA. Therefore, an accurate classification of marshes is vital for the productivity estimation (Ahl et al., 2005). Landsat thematic mapper (TM) images were classified using the Ecognition software (Shackelford and Davis, 2003) to extract marsh cover in 2010. All of the TM images