Ecological Modelling 312 (2015) 54–60

Contents lists available at ScienceDirect

Ecological Modelling

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

Quantitative assessment of human appropriation of aboveground net primary production in China

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ARTICLE INFO

Article history:
Received 8 January 2015
Received in revised form 15 May 2015
Accepted 15 May 2015
Available online 5 June 2015

Keywords:
HANPP
China
Sustainable development

ABSTRACT

Profound and long-lasting effects on ecosystems have occurred during the past three decades' development in China, which have threatened the country's sustainable development. The extent to which the biosphere's annual primary production has been altered by human intervention in China, however, is still unclear. Human appropriation of net primary production (HANPP) has gained great attention and been extensively used as an indicator of sustainability in recent decades. Through the combined use of statistical methods and remote-sensing data, the temporal and spatial features of HANPP in China have been investigated. From 2001 to 2010, HANPP in China increased remarkably, rising from 1.85 Pg C/yr to 2.44 Pg C/yr, an average annual increase of 3.15% per year. Population pressure and rapid economic development may explain this trend to a large degree. To achieve the goal of sustainable development and a "beautiful China," in the coming years more attention should be paid to increasing the efficiency of land use and biomass extraction, and reducing environmental pollution.

1. Introduction

Since China's economic reform process began in late 1978, China has witnessed extremely rapid economic development and great improvement in human welfare. This rapid economic expansion and population growth, however, also caused serious shortages of natural resources, environmental pollution, and ecological degradation, all of which threaten China's long-term growth and sustained development. Quantitative assessment of these human impacts, employing proper indices, is urgently needed to define a path toward China's sustainable development.

Human activities ultimately depend on the earth's net primary production (NPP) (Imhoff and Bounoua, 2006). Human appropriation of net primary production (HANPP) has gained credibility as an aggregated indicator that reflects not only the amount of land devoted to human use, but also the intensity of that use (Haberl et al., 2004a,b). It addresses the basic issue of how much of the biosphere's annual primary production has been appropriated by humans (Haberl et al., 2007; Peng et al., 2007; Ma et al., 2012). After Vitousek et al. (1986) gave the first comprehensive description of HANPP, many scientists calculated HANPP on global (Rojstaczer et al., 2001; Imhoff et al., 2004a,b; Haberl et al., 2007), national (Kastner, 2009; Kohlheb and Krausmann, 2009; Schwarzlmüller, 2009; Fetzel et al., 2014; Niedertscheider and Erb, 2014; Niedertscheider et al., 2014), and local scales (O'Neill et al., 2006). Global HANPP was estimated to be 15.6 Pg C/yr, or 23.8% of potential net primary production, of which 53% was attributed to the harvest of food and fiber, 40% by land-use-induced productivity changes, and 7% by human-induced fires (Haberl et al., 2007). The global distribution of HANPP varies enormously, ranging from nearly 0% of local NPP in sparsely populated areas to more than 30,000% in highly urbanized centers (Imhoff et al., 2004a,b). The variation in HANPP at the country level is also dramatic, and is due to the specific geographic and socio-economic situation of each country, including such phenomena as levels of economic output, economic and population growth, biomass use, and land-use intensity (Krausmann et al., 2012). China's HANPP plays an important role in sustainable development worldwide, and changes in its magnitude can significantly influence global biomass markets. It is, however, still poorly understood (Peng et al., 2007).

Using the social and economic statistical data available in China, and high-resolution remote-sensing technology, this study has the aims of calculating the total HANPP in China, and exploring the temporal and spatial variation of HANPP in China from 2001 to 2010. In addition, the study will also analyze the forces that drive HANPP in China.

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http://dx.doi.org/10.1016/j.ecolmodel.2015.05.017
0304-3800/

2. Methodology and materials

2.1. Definition and calculation of HANPP

HANPP is defined as the difference between the potential NPP that would be available in an ecosystem without human interference and the NPP left in the ecosystem after human harvesting (Schandl et al., 2002). We refer to the methodological principles outlined in Haberl et al. (2007) and Schwarzlmüller (2009), as shown in Fig. 1. Due to the large uncertainty in the data of belowground NPP (Schandl et al., 2002), we confined this study to the quantification of aboveground NPP. To calculate HANPP, some variables must first be determined, these include:

- Potential aboveground NPP available without human interference (NPP_0)
- Actually prevailing NPP in ecosystems (NPP_{act})
- Aboveground NPP harvested by humans (NPP_h)
- NPP remaining in ecosystems after harvest (NPP_t)

Human-induced land conversion change to aboveground NPP (ΔNPP_{lc}). Accordingly, HANPP can be calculated as follows (Fig. 1).

$$HANPP = NPP_0 - NPP_t, \quad \text{with} \quad NPP_t = NPP_{act} - NPP_h \qquad (1)$$

or

$$HANPP = \textit{Delta}\ NPP_{lc} + NPP_h, \quad \text{with} \quad \textit{Delta}\ NPP_{lc} = NPP_0 - NPP_{act} \qquad (2)$$

The calculation of HANPP is based on available information concerning land cover and land use, socio-economic activities of human biomass harvest, and the overall productivity of terrestrial ecosystems. The results indicated aboveground biomass flows only, and are presented in petagrams of carbon content per year (Pg C/yr). HANPP also is sometimes expressed as a percent of NPP_0.

2.2. Data sets

The data on population at national scales from 2001 to 2010 were collected from the Chinese National Bureau of Statistics (http://data.stats.gov.cn/) to calculate per capita HANPP. Yearly land use and land cover data were obtained from the MODIS Land Cover Type product (MCD12Q1) (Friedl et al., 2010), which provides criteria for characterizing five global land-cover classification systems. We choose the land-cover classification system defined by the International Geosphere Biosphere Programme (IGBP), which

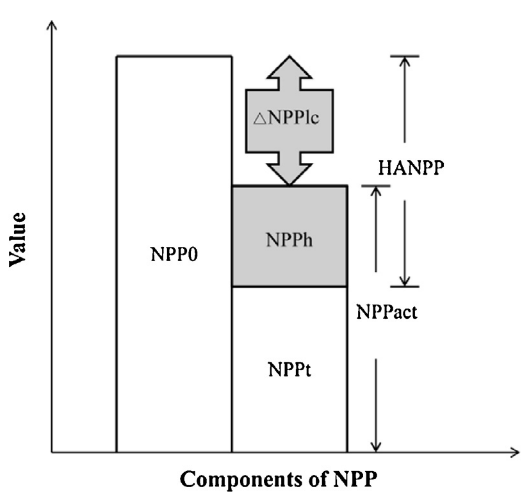

Fig. 1. Definition of HANPP and the relationships of its components, from Haberl (1997).

includes 11 natural vegetation classes, three developed and mixed-use land classes, and three non-vegetated land classes. These classes were aggregated to five land-use types, namely: cropland, grassland, forested land, built-up areas, and other land. The time series for each category was established independently. The required climate data, including temperature and precipitation, were downloaded from the website of China's Meteorological Data Sharing Service System (http://cdc.nmic.cn/home.do).

The actual aboveground NPP for China was obtained from MODIS data for the years 2001 to 2010, using a product named MOD17A3 (https://lpdaac.usgs.gov/data_access). Water bodies were considered only as a source of land conversion, i.e. water bodies had no specific productivity value attached to them, then the NPP on it was assumed to be zero (Kastner, 2009; Schwarzlmüller, 2009). Using ArcGIS technology supported by land-use and land-cover maps, the time series of NPP for different land-use types were extracted from the digital NPP maps.

NPP_h involves all aboveground biomass harvests attributable to socio-economic activities. Five functional types of NPP_h were distinguished, namely: cropland harvest, grazed biomass, wood harvest, harvest on built-up areas, and biomass burned by human-induced fire. Crop harvest and wood harvest also include residues (such as straw, whether used or left on site). Most of the biomass harvest data were collected from the United Nations Food and Agriculture Organization (FAO, http://www.fao.org/home/en/), the Chinese National Bureau of Statistics, and the China Forestry Statistical Yearbook from 2001 to 2010 on national level. The data in this study are given in Pg C/yr. As the carbon content of dry biological matter is 45% by weight (Schandl et al., 2002), the data calculated in the unit of Pg of dry biological matter/yr were multiplied the conversion factor of 0.45 to convert into Pg C/yr (Table 1).

2.3. Methodology

The NPP_0 for China from 2001 to 2010 was derived from a calculation based on the Guangsheng Zhou Model, which was derivates processed on similar procedure of Chikugo Model with some investigated materials that Efimova had collected during her work on IBP, concerning the characteristic of plant physioecology and evapotranspiration model (Zhou and Zhang, 1993; Zhou et al., 1998; Song et al., 2009). This decision was made despite the more complex models that are available, such as the empirical models (Miami model, Chikugo model, and Beijing model), solar-utilization models (CASA, GLOPEM, and GEOLUE) the ecosystems-process models (CEVSA and GEOPRO), and the well-established biogeochemical-process model of global vegetation (LPJ-DGVM). Compared with those models, Guangsheng Zhou model combines the ecological physicology and statistics, which integrated empirical and theoretical characteristics and has been confirmed more effective than Chikugo model especially on the arid and semi-arid area (Song et al., 2009; Zhang and Zhou, 2010; Sun et al., 2012) and has been widely used to calculate NPP at the national and regional scales of China, especially it was developed based on the fundamental situation of China (Zhou et al., 1998; Wang, 2008; Song et al., 2009; Li et al., 2011). In this study, the Guangsheng Zhou model was used to calculate the NPP_0 of each cell and the total NPP_0 of China.

NPP_h on cropland consists of the primary crop harvest, and the used and unused crop residues. It was calculated from the Chinese National Bureau of Statistics database. The data were converted to dry matter equivalents by using crop-specific data on water content, according to the literature (Haberl et al., 2007; Schwarzlmüller, 2009). Although harvest crop residues have not been recorded in any databases, they can be derived from primary crop harvest data using harvest indices and recovery rates (Wirsenius, 2000). The harvest index is the ratio of crop harvest to the total aboveground biomass of the specific type crop. The