

1 **Quantitative assessment of human appropriation of**
2 **aboveground net primary production in China**

3
4 **Authors:** Aifang Chen^a, Ruiyun Li^a, Honglin Wang^a, Bin He^{a,b,*}

5 ^aCollege of Global Change and Earth System Science, Beijing Normal University,
6 Beijing, 100875, China.

7 ^bState Key Laboratory of Earth Surface Processes and Resource Ecology, Beijing
8 Normal University, Beijing, 100875, China.

9 ***Corresponding Author:** Bin He, Lecturer, State Key Laboratory of Earth Surface
10 Processes and Resource Ecology and College of Global Change and Earth System
11 Science, Beijing Normal University, Beijing, 100875, China, Fax Number:
12 86-10-58802165, Telephone Number: 86-10-58808052, Email: hebin@bnu.edu.cn.

13
14 **Abstract:** Profound and long-lasting effects on ecosystems have occurred during the
15 past three decades' development in China, which have threatened the country's
16 sustainable development. The extent to which the biosphere's annual primary
17 production has been altered by human intervention in China, however, is still unclear.
18 Human appropriation of net primary production (HANPP) has gained great attention
19 and been extensively used as an indicator of sustainability in recent decades. Through
20 the combined use of statistical methods and remote-sensing data, the temporal and
21 spatial features of HANPP in China have been investigated. From 2001 to 2010,
22 HANPP in China increased remarkably, rising from 1.85 Pg C/yr to 2.44 Pg C/yr, an
23 average annual increase of 3.15% per year. Population pressure and rapid economic
24 development may explain this trend to a large degree. To achieve the goal of
25 sustainable development and a "beautiful China," in the coming years more attention
26 should be paid to increasing the efficiency of land use and biomass extraction, and
27 reducing environmental pollution.

28 **Keywords:** HANPP; China; Sustainable Development

30 **1. Introduction**

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

38 Human activities ultimately depend on the earth's net primary production (NPP)
39 (Imhoff and Bounoua, 2006). Human appropriation of net primary production
40 (HANPP) has gained credibility as an aggregated indicator that reflects not only the
41 amount of land devoted to human use, but also the intensity of that use (Haberl et al.,
42 2004a; Haberl et al., 2004b). It addresses the basic issue of how much of the
43 biosphere's annual primary production has been appropriated by humans (Haberl et al.,
44 2007b; Peng et al., 2007; Ma et al. 2012). After Vitousek et al. (1986) gave the first
45 comprehensive description of HANPP, many scientists calculated HANPP on global
46 (Rojstaczer et al., 2001; Imhoff et al., 2004; Haberl et al. 2007b), national (Kastner,
47 2009; Kohlheb and Krausmann, 2009; Schwarzmüller, 2009; Fetzel et al., 2014;
48 Niedertscheider and Erb, 2014; Niedertscheider et al., 2014), and local scales (O'Neill
49 et al., 2006). Global HANPP was estimated to be 15.6 Pg C/yr, or 23.8% of potential
50 net primary production, of which 53% was attributed to the harvest of food and fiber,
51 40% by land-use-induced productivity changes, and 7% by human-induced fires
52 (Haberl et al., 2007b). The global distribution of HANPP varies enormously, ranging
53 from nearly 0% of local NPP in sparsely populated areas to more than 30,000% in
54 highly urbanized centers (Imhoff et al., 2004). The variation in HANPP at the country
55 level is also dramatic, and is due to the specific geographic and socio-economic
56 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.

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; Haberl et al., 2007a). We refer to the methodological principles outlined in Haberl et al. (2007b) and Schwarzmüller (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})

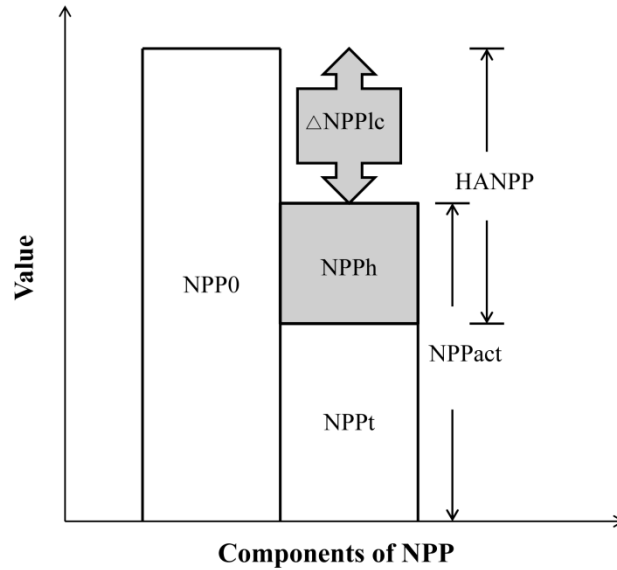
Accordingly, HANPP can be calculated as follows (Fig. 1).

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

or

85
$$\text{HANPP} = \Delta\text{NPP}_{\text{lc}} + \text{NPP}_{\text{h}}, \text{ with } \Delta\text{NPP}_{\text{lc}} = \text{NPP}_0 - \text{NPP}_{\text{act}} \quad (2)$$

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



91
 92 **Fig. 1.** Definition of HANPP and the relationships of its components, from Haberl (1997).

94 2.2. Data sets

95 The data on population at national scales from 2001 to 2010 were collected from
 96 the Chinese National Bureau of Statistics (<http://data.stats.gov.cn/>) to calculate per
 97 capita HANPP. Yearly land use and land cover data were obtained from the MODIS
 98 Land Cover Type product (MCD12Q1) (Friedl et al., 2010), which provides criteria
 99 for characterizing five global land-cover classification systems. We choose the
 100 land-cover classification system defined by the International Geosphere Biosphere
 101 Programme (IGBP), which includes 11 natural vegetation classes, three developed
 102 and mixed-use land classes, and three non-vegetated land classes. These classes were
 103 aggregated to five land-use types, namely: cropland, grassland, forested land, built-up
 104 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; Schwarzmüller, 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
Summary of data sources associated with HANPP

Variable	Unit	Description / Data sources
Population	persons	National Bureau of Statistics of China
Temperature	°C	China Meteorological Data Sharing Service System
Precipitation	mm	China Meteorological Data Sharing Service System
MOD17A3	kg C/m ²	The actual aboveground NPP of China

Cropland Production	tonnes	National Bureau of Statistics of China
Livestock Production	head	FAOSTAT 2013
Wood Production	10 thousand cubic meters	National Bureau of Statistics of China and China Forestry Statistical Yearbook
Biomass burned by human-induced fire	tonnes	FAOSTAT 2013 (dry matter)

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 derivatives 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 physiology 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., 2007b;

Schwarzmüller, 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 recovery rates are defined as the proportion of the total crop residues used (Schwarzmüller, 2009). Harvest indices and recovery rates are according to Schwarzmüller (2009) and Haberl et al. (2007b).

Owing to few recorded data on appropriation of grassland, the amount of NPP_h on annually grazed biomass was counted as the difference between livestock's feed demand and the feed supply (Haberl et al., 2007b; Krausmann et al., 2008; Erb et al., 2009). In this study, we considered only the feed demand of the grass-feeding livestock and feed supply of coarse forage. Because livestock such as swine and poultry are typically fed commercial feed instead of grass fodder, only asses, horses, mules, cattle (including buffalo), sheep, and goats were counted as livestock. The data for livestock production came from FAO databases. The yearly production numbers for asses, horses, mules, cattle and buffalo, sheep, and goats were converted into standard sheep units, with each individual of the other livestock types taken as equal to five sheep units. Each sheep unit needs 1.8 kilograms of dry-matter coarse forage per day. Coarse forage includes straw fodder and grass fodder (Zhang et al., 2014). The straw fodder consists of grains, pulses, and straw, and grass fodder consists of grass in natural and manmade grasslands. Further, straw fodder was calculated by the cereal's production and the conversion coefficient of straw, applying the 25% straw utilization factor (Zhang et al., 2014). The conversion coefficients for rice, wheat, maize, millet, sorghum, other cereals, and pulses are 0.9, 1.1, 1.2, 1.6, 1.8, 1.6, and 1.5 respectively (Zhang et al., 2014). The feed supply of grassland is equal to feed demand minus feed supply of straw fodder, thus enabling the calculation of grassland appropriated annually. The data for the production of cereals were derived from the Chinese National Bureau of Statistics.

Data download from the Chinese National Bureau of Statistics was used to calculate the NPP_h for forestry or wood harvested. The category includes total timber and bamboo production, farmers' self-use felling, and fuel wood for farmers. The data for 2003 were missing, so they were derived by linear regression from the data in the other years. Considering the method of Haberl et al. (2007b), we calculated felling losses, which were considered to be felling minus removal, using a recovery rate of 48% for both coniferous and deciduous trees. Wood density was used to convert fresh timber to dry biological matter. The calculated forestry production results included the harvest of rubber, turpentine, raw lacquer, tung seed, and camellia seed. For those products, the difference between total harvest and removed harvest was considered marginal, and was not calculated (Schwarzlmüller, 2009).

According to Haberl et al. (2007b), NPP_h of a built-up area, such as the biomass harvest during gardening, park, and infrastructure maintenance is equal to 50% of NPP_{act} of the built-up area. We used the amount of built-up area obtained from the MODIS NPP_{act} data land-cover maps to extract the NPP_{act} of built-up areas. Data on NPP_h for burning biomass were taken from FAO databases, which consisted of humid tropical forest, other forests, and organic soils.

The data used to calculate NPP_h , for example, the amount of grain production, livestock production, and timber felling, were downloaded from FAO databases and the Chinese National Bureau of Statistics, but the data were not identical due to the different statistical standard of each statistical bureau. Data downloaded from the websites were used to perform our own calculations, such as using harvest indices and recovery rates to measure harvest crop residues. The harvest index is the ratio of crop harvested to the total aboveground biomass of the specific type crop (Schwarzlmüller, 2009). The recovery rates were defined as the proportion of the total crop residues used. Harvest indices and recovery rates were taken from Schwarzlmüller (2009) and Haberl et al. (2007b). The data may have some gaps, because Schwarzlmüller studied Spain from 1955 to 2003, and Haberl studied East Asia in 2000.

We followed the ‘HANPP efficiency’ definition from Fetzel et al. (2014), which is the share of used extraction (NPP_h) in total HANPP: $NPP_h/HANPP$, to analyze the efficiency of HANPP used in total and in different land use categories. A high HANPP efficiency is related to a high share of NPP_h to total HANPP because the bulk of the appropriated biomass enters the socio-ecological system, while a low HANPP efficiency occurs when ΔNPP_{lc} is high (Fetzel et al., 2014).

3. Results

Fig. 2 illustrates the spatial distribution of averaged NPP_0 and NPP_{act} from 2001 to 2010. The maps of NPP_0 and NPP_{act} presented similar distribution characteristics, with a decreasing trend from southeast to northwest. The nonvegetated areas in northwest China had a value close to zero. The national averaged NPP_0 was 3.90 Pg C/yr, and the national averaged NPP_{act} was 3.24 Pg C/yr. It can be seen from Fig. 3 that both the NPP_0 and NPP_{act} slightly increased with fluctuations from 2001 to 2010. Overall, NPP_0 increased slightly from 3.73 Pg C in 2001 to 4.23 Pg C in 2010, with the highest value reached in 2010. NPP_{act} in China exhibited a wavelike rise, but not a significant one, as it fluctuated between 3.00 Pg C/yr and 3.36 Pg C/yr.

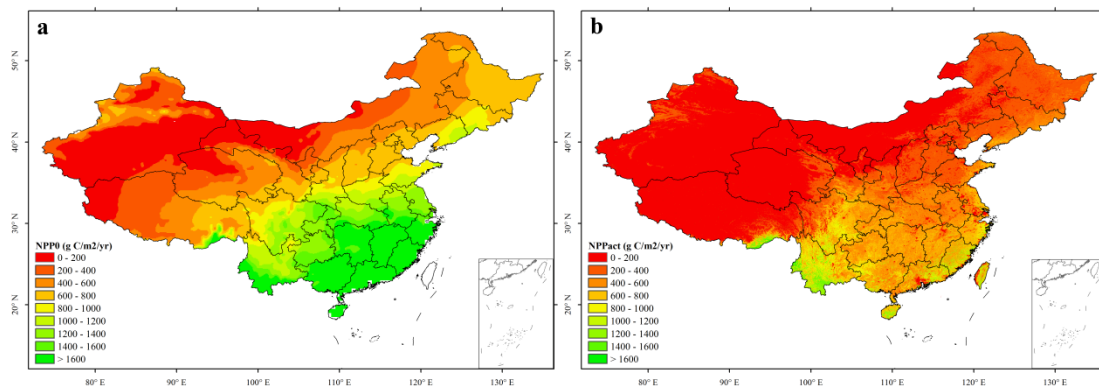


Fig. 2. Spatial distributions of NPP_0 (a) and NPP_{act} (b) in China from 2001 to 2010.

The values for ΔNPP_{lc} were derived from the difference between NPP_0 and NPP_{act} , and they showed a fluctuating upward trend, increasing from 0.73 Pg C in 2001 to 1.07 Pg C in 2010, for an annual growth rate of 4.42%. As one of the most

important components of HANPP, NPP_h increased from 1.12 Pg C/yr to 1.37 Pg C/yr during the period of 2001 to 2010. It can be decomposed into several parts, according to different land-use categories (Table 2). The large increase of grassland, cropland, and forested area biomass contributed to this change. Grassland biomass made a significant contribution, which amounted to more than half of total NPP_h . The harvest from cropland was the second most significant contribution, representing more than 30 percent. The trends of biomass harvested from cropland, grassland, and forested areas are all characterized by an increase, with annual growth rates of 2.36%, 2.31%, and 10.17%, respectively. The rate of increase in biomass harvested from forested areas was the largest. The proportion of biomass harvest on built-up areas through gardening and park development amounted to approximately 10% of total NPP_h ; this proportion has decreased in recent years. In addition, the proportion of biomass burned cannot be ignored, though it accounts only for about 0.23%.

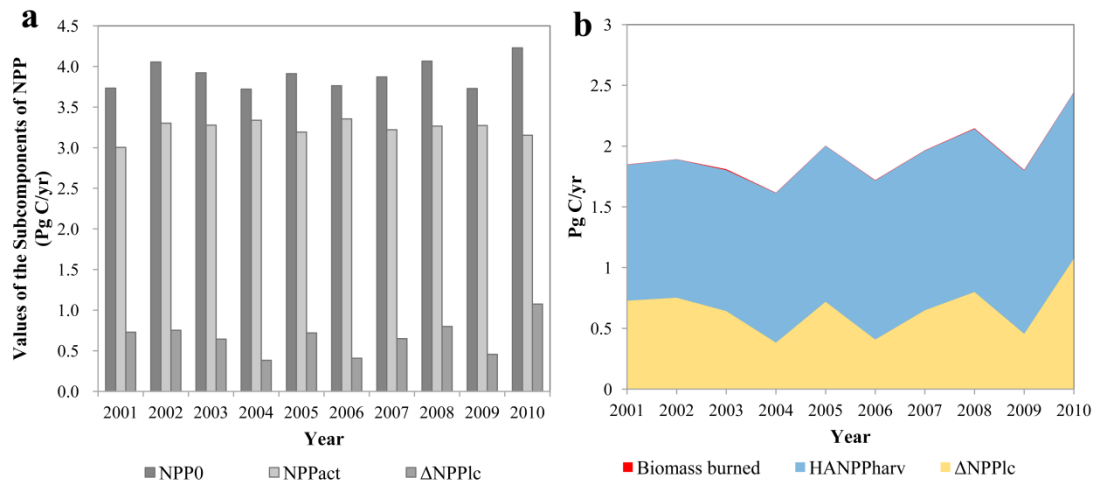


Fig. 3. Components of NPP (a) and trends in HANPP (b) in China from 2001 to 2010.

HANPP is the sum of ΔNPP_{lc} and NPP_h (Fig. 3b). The rise in both ΔNPP_{lc} and NPP_h drove HANPP that climbed from 1.85 Pg C/yr (49.54% of NPP_0) to 2.44 Pg C/yr (57.80% of NPP_0), with an average value of 1.93 Pg C/yr over the period. Relative to NPP_0 and in per capita terms, HANPP grew with subtitle wave-like trend over the study period (Fig. 4a). HANPP per capita rose from 1.45t C/cap/yr to 1.82 t

252 C/cap/yr from 2001 to 2010, with an annual growth rate of 2.58%.

Table 2

Biomass harvest (NPP_h) by land-use category

Year	Grassland		Crop land		Forestry land		Built-up area		Biomass burned		Total NPP_h
	value	%	value	%	value	%	value	%	value	%	
2001	0.5981	53.36	0.3774	33.67	0.0164	1.47	0.127	11.33	0.0019	0.17	1.1208
2002	0.607	53.28	0.3862	33.89	0.0173	1.51	0.128	11.24	0.0009	0.08	1.1393
2003	0.6408	54.89	0.3674	31.48	0.0232	1.99	0.1284	11	0.0075	0.64	1.1673
2004	0.6782	55	0.3985	32.32	0.0253	2.05	0.1288	10.44	0.0022	0.18	1.2331
2005	0.7181	55.93	0.4096	31.9	0.027	2.11	0.128	9.97	0.0012	0.09	1.2840
2006	0.7296	55.63	0.4192	31.96	0.0321	2.44	0.1283	9.78	0.0025	0.19	1.3116
2007	0.7286	55.37	0.4231	32.15	0.0338	2.57	0.1281	9.74	0.0022	0.17	1.3158
2008	0.7253	53.85	0.4499	33.41	0.0391	2.9	0.1283	9.53	0.0042	0.31	1.3468
2009	0.7292	54.08	0.4532	33.61	0.0344	2.55	0.1278	9.48	0.0038	0.29	1.3484
2010	0.7346	53.64	0.4657	34.01	0.0392	2.86	0.128	9.35	0.0018	0.13	1.3693

253

254 During the time period, the HANPP efficiency ($NPP_h/HANPP$) showed
255 fluctuates but decreasing trend on the whole, with an annual decrease rate of 0.87%,
256 and the HANPP intensity, proportion of ΔNPP_{lc} to HANPP, rose from 39.39% at the
257 beginning to 43.98% in the end. The trend of HANPP efficiency in different land use
258 categories (except biomass burned) were displayed in Fig. 4b, with the highest
259 efficiency over 80% in urban area, while the lowest one is forestry less than 10%.
260 However, massive increases in efficiency were found on forestry, which grew from
261 2.37% to 4.63%, with annual growth rate of 7.71%. Increases were also found in
262 cropland and grassland, which followed forestry listed in second and third, with
263 annual growth rate of 0.56% and 0.28%, respectively, indicating that the ΔNPP_{lc} fell
264 over the time period. However, there was a slight reduce in urban area, from 89.95%
265 in 2001 reduced to 87.92% in 2010.

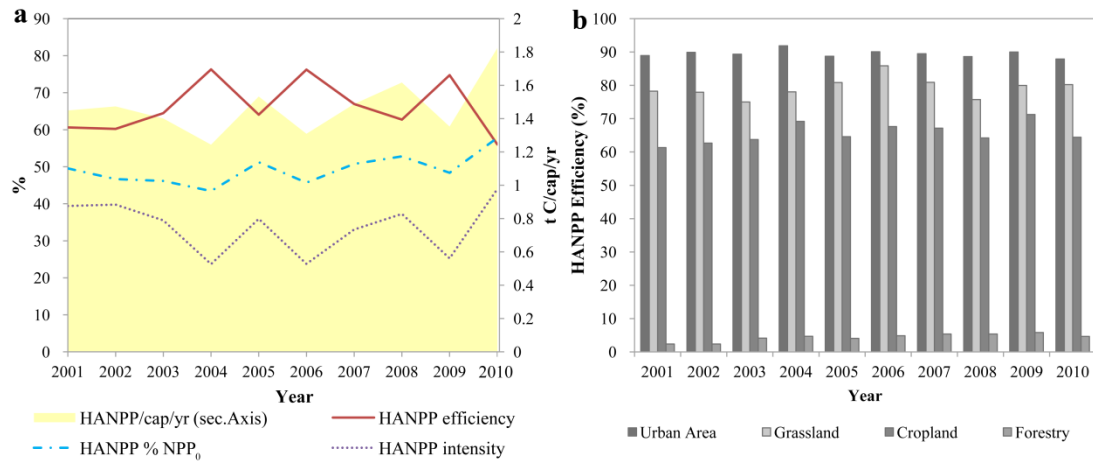


Fig. 4. Indicators of HANPP for China 2001-2010. (a) Indicator of HANPP on total: HANPP efficiency, HANPP intensity, HANPP as a percentage of NPP₀; Secondary axis: per capita of HANPP. (b) HANPP efficiency on land use classes.

4. Discussion

Miami model relies on the experimental data of NPP, which were calculated using the temperature and precipitation data of the nearest meteorological stations, and covered 52 ecosystems (Liu, 1997; Fang et al., 2000). However, the results always higher than the actual (Song et al., 2009), though it has proven effective for scientific studies, and been widely used to calculate NPP at the country and regional scales (Chen, 1987; Mingcan and Jiali, 2001; Shanlei et al., 2010; Mei, 2012). In our study, the results of Miami model is the highest one, compared with Guangsheng Zhou model and previous studies (Haberl et al., 2007b; Imhoff, 2004). Guangsheng Zhou model was developed on the basis of Chikugo model and integrated empirical and theoretical characteristics, which has been confirmed more effective than Chikugo model especially on the arid and semi-arid area (Song et al., 2009; Sun et al., 2012). Hence, the results processed by it was applied by this study, which is consistent with the data in Haberl et al. (2007b).

HANPP is a measure to evaluate the extent to which humans perturb ecosystems, accounting for the influence of human-induced changes in land use and land cover, and the extraction of biomass by humans. HANPP values in China, as observed in this

study, have been increasing, and currently account for approximately 58% of NPP_0 , while it was about 62% in 2000, according to Haberl et al. (2007b) (Table S1). The value of HANPP in our study was 1.85 Pg C in 2001 which is consistent with previous results according to Socioeconomic Data and Applications Center that it was 1.62 Pg C/yr in 1995 in Imhoff et al. (2004). Compared with those countries, such as Austria (Krausmann, 2001), the Philippines (Kastner, 2009), the United Kingdom (Musel, 2009), Spain (Schwarzmüller, 2009), Hungary (Kohlheb and Krausmann, 2009), South Africa (Niedertscheider et al., 2012), Italy (Niedertscheider and Erb, 2014), Germany (Niedertscheider et al., 2014), and New Zealand (Fetzel et al., 2014), HANPP of China to NPP_0 was at a rationale scale, considering the largest population and low proportion of arable land (Table 3).

Table 3

Overview of previous work on HANPP at different scales

Work	Study scale	Study period	HANPP (% NPP_0 on 2000)
Vitousek et al. (1986) intermediate	Global	1970s	30.7
Rojstaczer et al. (2001)	Global	1980s-1990s	32 (10-55)
Imhoff et al. (2004)	Global	1995	14.1-26.07
Imhoff et al. (2006)	Global	1995	28.6-55.6
Haberl et al. (2007)	Global	2000	23.8
Krausmann (2001)	Austria	1830-1995	51
Musel (2009)	United Kingdom	1800-2000	68
Kastner (2009)	Philippines	1910-2003	62
Schwarzmüller (2009)	Spain	1955-2003	62±9
Kohlher and Krausmann (2009)	Hungary	1961-2005	71
Niedertscheider et al. (2012)	South Africa	1961-2006	21
Niedertscheider et al. (2014)	Germany	1883-2007	56
Niedertscheider and Erb et al. (2014)	Italy	1884-2007	56
Fetzel et al. (2014)	New Zealand	1860-2005	55

Regarding the relative influence of NPP_h and ΔNPP_{lc} on China's HANPP, the

study found that NPP_h was the dominating factor from 2001 to 2010, with an average percent of 66.24 to HANPP. In addition, NPP_h in China accounted for 32.43% of NPP_0 from 2001 to 2010. This compares with the 2000 global average of 20.4% is reasonable. However, as to ΔNPP_{lc} factor, with 16.81% of NPP_0 , which was far more than the global average of 5% in 2000 (Kastner, 2009) is evident that human-induced change in land cover play an important role in HANPP which suggest that the needs of raising the concern of protecting environment and the government should pay close attention to reduce human-induced changes in land cover, and the environmental degradation that attends them, account for the gap between NPP_0 and NPP_{act} , especially on the condition that the HANPP efficiency was dropping in recent years.

China's high HANPP value reflects the three factors: China is the world's most populous country, China has very intense land use, and China has experienced rapid economic development. Economic conditions affect HANPP, as a rising standard of living will entail higher per capita food consumption. For example, more NPP is required to produce meat than to produce the same amount of vegetable food. In developed economies such as that of the United States, per capita food consumption is several times that of developing countries (Li and Cheng, 2000). Economic development also usually correlates with high levels of urbanization and carbon emissions.

Fig. 5 shows the trends in GDP, carbon emissions, and urbanization rate in China, which exhibited growth rates of 15.51%, 10.09%, and 3.19%, respectively, for the period studied. Compared with those indicators of economic development, the annual growth rates of China's population was subtle, only 0.55%. Although China's family planning policies have limited the country's population growth to only 0.55%, due to its enormous population base, within the next 10 years China's population will grow by about 64.64 million, more than the current population of either Spain, the United Kingdom, Hungary, or South Africa. China's growing population may contribute to an

increase of HANPP, but economic development will play a more important role. From 2001 to 2010, the average annual rate of GDP growth was 9.5%, while GDP and carbon emissions increased by about 3.66-fold and 2.38-fold, respectively. However, higher HANPP does not certify the unsustainable development of China, taking account of the improvement of people's life standard in China. In the following work, we will put strength to quantize the relationship between life standard and the sustainable development.

In addition, technological development, such as that which could increase the efficiency of land use, could increase the amount of NPP appropriation. Therefore, China's rapid economic growth and relatively slow population growth did not cause the increase in HANPP equally. In East Asia, the Philippines, the United Kingdom, Spain, Hungary, and South Africa, the ratio of HANPP to NPP_0 decreased despite increasing population, mostly because their efficiency at harvesting biomass increased. This study also found that increasing land-use efficiency is a way to solve the conflict between an increasing population and limited land resources (Kastner, 2009; Musel, 2009; Schwarzmüller, 2009). During the past few decades, the government of China has enacted a series of policies with the aim of achieving a "Beautiful China." These policies involve sustainable development, increasing land-use efficiency and the rate of biomass extraction, controlling population growth, and decreasing environmental pollution.

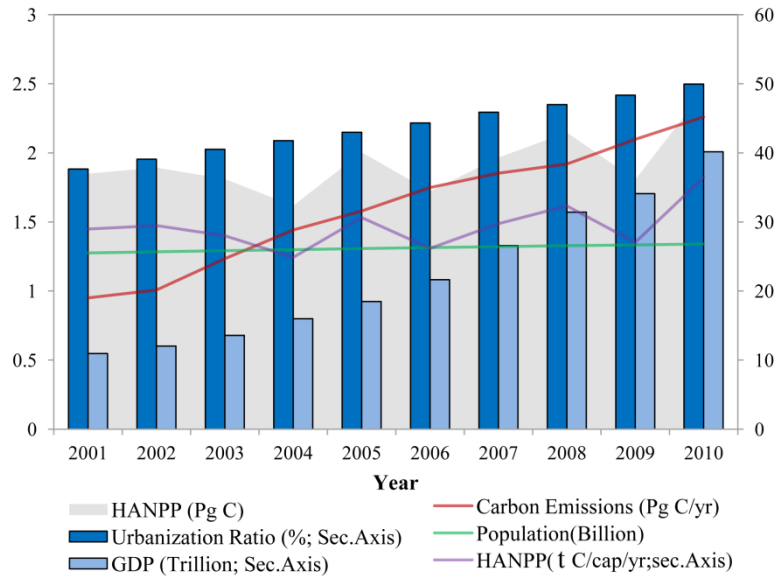


Fig. 5. Comparison of indicators 2001-2010. HANPP in Pg C/yr, Carbon Emission in Pg C/yr and Population in billion; Secondary axis: Urbanization ratio in percentage, GDP in trillion, per capita HANPP in t C/cap/yr.

This study employed a wide range of data sets, such as the gaps between FAO and China National Bureau of Statistics on cropland, grass land and forestry, will add some data quality issues, specifically due to the different statistic method. Though we derived the missing data in forestry year book by linear regression from the data in the other years, there may be some gaps between the real data and the result. And the NPP_h on cropland consists of the primary crop harvest, and the used and unused crop residues were calculated from the Chinese National Bureau of Statistics database and the convert indices from fresh to dry matter were using crop-specific data on water content, according to the literature, which also lead to some uncertainty. However, the global and national results from Krausmann et al. (2013) and Fetzel et al. (2014) indicate that the impact is not strong enough to significantly alter general trajectories and interpretation. Despite these limitations caused by data quality, it is sensible to believe our results are robust, since the aim of our study is to contribute to a discussion of general trajectories change in China.

5. Conclusions

In this study, we quantitatively assessed the human appropriation of aboveground net primary production in China from 2001 to 2010. Our results showed that HANPP was characterized by an increasing trend, which rose from 49.54% to 57.80% of the potential NPP, for an average annual growth rate of 1.73%. Although its absolute value is a bit large, the rate of increase is not remarkable. An enormous population and rapid economic development serve to explain the amount of HANPP in China, which is the world's largest. Still the improvement of people's life in China which was in accordance with sustainable development in China, though it may lead to the HANPP increases. We now must turn to the question of how much more China will appropriate in the coming decades and what's the relationship between improving life standard and sustainable development.

6. Acknowledgements

This work is financially supported by the National Basic Research Development Program of China (grant no. 2011CB952001 and 2012CB95570001) and the National Natural Science Foundation of China. I wish to thank Helmut Haberl and Wenquan Zhu for his kindness in answering my questions, and Xiaolei Liu for his help in preparing the manuscript.

7. References

- Chen, G. 1987. Preliminary study on calculation of primary production of exosystem in China with application of Miami model. *Journal of Natural Resources* 2:270-278(In Chinese).
- Erb, K.-H., F. Krausmann, V. Gaube, S. Gingrich, A. Bondeau, M. Fischer-Kowalski, and H. Haberl. 2009. Analyzing the global human appropriation of net primary production — processes, trajectories, implications. An introduction. *Ecological Economics* 69:250-259
- Fang, J., Y. Tang, J. Lin, and G. Jiang. 2000. *Global Ecology: Climate Change and Ecological Responses* China Higher Education Press and Springer-Verlag, Beijing and Heidelberg.
- Fetzel, T., M. Gradwohl, and K.-H. Erb. 2014. Conversion, intensification, and abandonment: A human appropriation of net primary production approach to analyze historic land-use dynamics in New Zealand 1860–2005. *Ecological Economics* 97:201-208
- Friedl, M. A., D. Sulla-Menashe, B. Tan, Schneider, A., , N. Ramankutty, A. Sibley, and X. Huang. 2010. MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets. *in* R. S. o. Environment, editor.
- Haberl, H. 1997. Human appropriation of net primary production as an environmental indicator:

405 implications for sustainable development. *Ambio* 26:143-146.

406 Haberl, H., K.-H. Erb, and F. Krausmann. 2007a. Human appropriation of net primary production
407 (HANPP). *International Society for Ecological Economics*

408 Haberl, H., K.-H. Erb, F. Krausmann, V. Gaube, A. Bondeau, C. Plutzer, S. Gingrich, W. Lucht,
409 and M. Fischer-Kowalski. 2007b. Quantifying and mapping the human appropriation of
410 net primary production in earth's terrestrial ecosystems. *Proc Natl Acad Sci U S A*
411 **104**:12942-12947

412 Haberl, H., N. B. Schulz, C. Plutzer, K. H. Erb, F. Krausmann, W. Loibl, D. Moser, N. Sauberer, H.
413 Weisz, H. G. Zechmeister, and P. Zülka. 2004a. Human appropriation of net primary
414 production and species diversity in agricultural landscapes. *Agriculture, Ecosystems &*
415 *Environment* **102**:213-218

416 Haberl, H., M. Wackernagel, F. Krausmann, K.-H. Erb, and C. Monfreda. 2004b. Ecological
417 footprints and human appropriation of net primary production: a comparison. *Land Use*
418 *Policy* **21**:279-288

419 Imhoff, Marc L., Lahouari Bounoua, Taylor Ricketts, Colby Loucks, Robert Harriss, and William
420 T. Lawrence. 2004. Human Appropriation of Net Primary Productivity (HANPP) by
421 Country and Product. Data distributed by the Socioeconomic Data and Applications
422 Center (SEDAC): <http://sedac.ciesin.columbia.edu/es/hanpp.html>.

423 Imhoff, M. L., and L. Bounoua. 2006. Exploring global patterns of net primary production carbon
424 supply and demand using satellite observations and statistical data. *Journal of*
425 *Geophysical Research* **111**

426 Imhoff, M. L., L. Bounoua, T. Ricketts, C. Loucks, R. Harriss, and W. T. Lawrence. 2004. Global
427 patterns in human consumption of net primary production. *Nature* **429**:867-870

428 Kastner, T. 2009. Trajectories in human domination of ecosystems: Human appropriation of net
429 primary production in the Philippines during the 20th century. *Ecological Economics*
430 **69**:260-269

431 Kohlheb, N., and F. Krausmann. 2009. Land use change, biomass production and HANPP: The
432 case of Hungary 1961–2005. *Ecological Economics* **69**:292-300

433 Krausmann, F. 2001. Land use and industrial modernization: an empirical of human influence on
434 the functioning of ecosystems in Austria 1830-1995. *Land Use Policy*:17-26

435 Krausmann, F., K.-H. Erb, S. Gingrich, C. Lauk, and H. Haberl. 2008. Global patterns of
436 socioeconomic biomass flows in the year 2000: A comprehensive assessment of supply,
437 consumption and constraints. *Ecological Economics* **65**:471-487

438 Krausmann, F., K. H. Erb, S. Gingrich, H. Haberl, A. Bondeau, V. Gaube, C. Lauk, C. Plutzer, and
439 T. D. Searchinger. 2013. Global human appropriation of net primary production doubled
440 in the 20th century. *Proc Natl Acad Sci U S A* **110**:10324-10329

441 Krausmann, F., S. Gingrich, H. Haberl, K. H. Erb, A. Musel, T. Kastner, N. Kohlheb, M.
442 Niedertscheider, and E. Schwarzmüller. 2012. Long-term trajectories of the human
443 appropriation of net primary production: Lessons from six national case studies. *Ecol*
444 *Econ* **77**:129-138

445 Li, H., B. Zhou, L. Li, and Z. Wang. 2011. Change pattern and its future trend of vegetation net
446 primary productivity on Qinghai Plateau. *Chinese Journal of Ecology* **30**:215-220(In

Chinese).

Li, L., and S. Cheng. 2000. Ecological footprint: a new indicator for sustainability. *Journal of Natural Resources* **15**:375-382

Liu, H. 1997. The Ecological Application of Miami Model. *Ecological Science* **16**:52-55(In Chinese).

Ma, T., C. Zhou, and T. Pei. 2012. Simulating and estimating tempo-spatial patterns in global human appropriation of net primary production (HANPP): A consumption-based approach. *Ecological Indicators*:660-667

Mei, N. 2012. Analysis on Net Primary Productivity of Natural Grassland in Guoluo Based on Miami Model. *Animal Husbandry and Feed Science* **33**:13(In Chinese).

Mingcan, L., and Q. Jiali. 2001. Calculation of Forest Potential Productivity for Tianshan Forest Region. *Journal of Forestry Research* **12**:73-74

Musel, A. 2009. Human appropriation of net primary production in the United Kingdom, 1800–2000. *Ecological Economics* **69**:270-281

Niedertscheider, M., and K. Erb. 2014. Land system change in Italy from 1884 to 2007: Analysing the North-South divergence on the basis of an integrated indicator framework. *Land Use Policy* **39**:366-375

Niedertscheider, M., S. Gingrich, and K.-H. Erb. 2012. Changes in land use in South Africa between 1961 and 2006: an integrated socio-ecological analysis based on the human appropriation of net primary production framework. *Regional Environmental Change* **12**:715-727

Niedertscheider, M., T. Kuemmerle, D. Muller, and K. H. Erb. 2014. Exploring the effects of drastic institutional and socio-economic changes on land system dynamics in Germany between 1883 and 2007. *Glob Environ Change* **28**:98-108

O'Neill, D. W., P. H. Tyedmers, and K. F. Beazley. 2006. Human appropriation of net primary production (HANPP) in Nova Scotia, Canada. *Regional Environmental Change* **7**:1-14

Peng, J., Y. Wang, and J. Wu. 2007. Human Appropriation of Net Primary Production: An Approach for Ecological Assessment of Regional Sustainable Development. *Journal of Natural Resources* **22**:153-158(In Chinese).

Rojstaczer, S., S. M. Sterling, and N. J. Moore. 2001. Human appropriation of photosynthesis products. *Science* **294**:2549-2552

Schandl, H., C. M. Grunbuhel, H. Haberl, and H. Weisz. 2002. Handbook of Physical Accounting Measuring bio-physical dimensions of socio-economic activities MFA – EFA - HANPP. Social Ecology Working Paper 73, Vienna.

Schwarzlmüller, E. 2009. Human appropriation of aboveground net primary production in Spain, 1955–2003: An empirical analysis of the industrialization of land use. *Ecological Economics* **69**:282-291

Shanlei, S., Z. Suoquan, S. Jianhong, L. Yi, X. Genyuan, L. Anwei, and L. Hongli. 2010. Calculation and Comparison of Vegetation Net Primary Productivity (NPP) in Zhejiang Province with Three Models. *Chinese Journal of Agrometeorology* **31**:271-276(In Chinese).

Song, F., M. Kang, Y. Chen, P. Yang, Y. Liu, and Q. Wang. 2009. Estimation of vegetation net

489 primary productivity on North Shaanxi Loess Plateau. Chinese Journal of Ecology
490 **28**:2311-2318(In Chinese).

491 Sun, J., D. Guan, J. Wu, C. Jin, and F. Yuan. 2012. Research advances in net primary productivity
492 of terrestrial vegetation. World Forestry Research **25**:1-6(In Chinese).

493 Vitousek, P. M., P. R. Ehrlich, A. H. Ehrlich, and P. A. Matson. 1986. Human appropriation of the
494 products of photosynthesis. BioScience **36**:368-373

495 Wang, S. 2008. Computation and analysis about NPP in Urumqi area based on 5 kinds of
496 climate-productivity model. Desert and Oasis Meteorology **2**(In Chinese).

497 Wirsenius, S. 2000. Human use of land and organic materials, Modeling the turnover of biomass
498 in the global food system. Chalmers University of Technology and Goteborg University,
499 **Goteborg, Sweden.**

500 Zhang, Y., Y. Zhang, L. Pan, S. Tang, and D. Huang. 2014. Analysis on current situation of
501 herbivorous livestock forage supply/demand in China. Chinese Journal of Animal Science
502 **50**:12-16(In Chinese).

503 Zhang, Y., and G. Zhou. 2010. Exploring the effects of water on vegetation change and net
504 primary productivity along the IGBP Northeast China Transect. Environmental Earth
505 Sciences **62**:1481-1490

506 Zhou, G., and X. Zhang. 1993. A natural vegetation NPP model. Acta Phytocologica Sinica
507 **19**:193-200(In Chinese).

508 Zhou, G., Y. Zheng, S. Chen, and T. Luo. 1998. NPP model of natural vegetation and its
509 application in China. Scientia Silvae Sinicae **34**:2-11(In Chinese).