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Assessing the impact of urbanization on regional net primary productivity in Jiangyin County, China

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Abstract

Urbanization is one of the most important aspects of global change. The process of urbanization has a significant impact on the terrestrial ecosystem carbon cycle. The Yangtze Delta region has one of the highest rates of urbanization in China. In this study, carried out in Jiangyin County as a representative region within the Yangtze Delta, land use and land cover changes were estimated using Landsat TM and ETM+ imagery. With these satellite data and the BEPS process model (Boreal Ecosystem Productivity Simulator), the impacts of urbanization on regional net primary productivity (NPP) and annual net primary production were assessed for 1991 and 2002. Landsat-based land cover maps in 1991 and 2002 showed that urban development encroached large areas of cropland and forest. Expansion of residential areas and reduction of vegetated areas were the major forms of land transformation in Jiangyin County during this period. Mean NPP of the total area decreased from 818 to 699 $g\,C\,m^{-2}\,yr^{-1}$ during the period of 1991 to 2002. NPP of cropland was only reduced by 2.7% while forest NPP was reduced by 9.3%. Regional annual primary production decreased from 808 Gg C in 1991 to 691 Gg C in 2002, a reduction of 14.5%. Land cover changes reduced regional NPP directly, and the increasing intensity and frequency of human-induced disturbance in the urbanized areas could be the main reason for the decrease in forest NPP.

Keywords: Urbanization; Land use and land cover change; Landsat imagery; Remote sensing; NPP; BEPS

1. Introduction

As human societies develop, their ecological and environmental influence has been steadily increasing. Following the industrial revolution, the scope of human impacts on nature expanded from local scale to regional and global scales. The present magnitude and rate of global ecosystems change is unprecedented. Previous studies on human modification of the landscape estimated that about one third to one half of the earth's land surface had been transformed by man (Vitousek et al., 1997). Land use and land cover change (LUCC) has been recognized as one of the most important aspects of global change. Many studies showed that LUCC affected the global system in various ways, including the atmospheric composition and processes (Keller et al., 1991), regional climate (Carlson and Arthur, 2000; Lean, 1989; Vitousek, 1994), soil quality (Islam and Weil, 2000), hydrology (Gornitz et al., 1997; Weber et al., 2001), and biodiversity (Crist et al., 2000; Myers, 1993).

It is increasingly recognized that global climate changed rapidly due to the increase of greenhouse gas concentration in the atmosphere (Karl and Trenberth, 2003). Since CO_2 is a major greenhouse gas that is also produced through fossil fuel consumption, human-induced land use and land cover change have exerted large impacts on the global carbon cycle (Houghton, 1995; Houghton et al., 1999; Detwiler, 1986; DeFries et al., 1999; Mann, 1986). For example, global land use change was estimated to release 1.6 ± 0.7 Pg C per year ($1\,Pg = 10^{15}\,g$) to the atmosphere during the 1980s (Houghton, 1995, 1996a, b). As an important aspect of LUCC, urbanization altered the composition and structure, and consequently affected the process and function of the ecosystems (Alberti, 2005;

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McDonnell et al., 1997). More attention is being given to the effects of urbanization recently. Despite CO_2 emission from fossil fuel combustion in urban areas and increased carbon concentration in the atmosphere, urban sprawl occupies the most fertile and productive land throughout the world (Nizeyaimana et al., 2001). Land transformation taking place during urbanization, such as clearing of forest and conversion of grassland to cropland, not only decreases vegetation carbon storage directly but also reduces soil carbon stock (Burke et al., 1991), thus transforming carbon sinks to sources (Houghton, 1995). Studies of urbanization effects would help understand dynamics and feedbacks of carbon cycles and ecosystem-adaptive mechanisms in response to global change, help predict future global carbon cycle trend, and support assessments of CO_2 fertilization effects and soil carbon balance.

In this paper, we focus on regional ecosystem net primary productivity (NPP). The energy flow in ecosystems starts at solar energy fixed by primary production of plants through the process of photosynthesis, and between 10% and 55% of the annual products of photosynthesis are appropriated by human beings (Rojstaczer et al., 2001; Vitousek et al., 1986). NPP is the primary source of food for humans and other heterotrophic organisms. As an important parameter of ecosystem functioning and the carbon cycle, NPP could be used as a "common currency" for quantifying the impact of land transformation across a broad spectrum of issues in earth system science and global change research (Imhoff et al., 2004). NPP is also used to quantify ecosystem service values (Björklund et al., 1999). Numerous studies have been published on NPP distribution and its variation in response to climate change (Churkina and Running, 1998; Raich et al., 1991; Woodward et al., 1995). A methodology for estimating NPP accurately at landscape, regional, continental and global scales under the influence of urbanization is crucial not only for carbon cycle research but also for government decision-making and region management. However, limited research has so far been carried out on quantifying urbanization effects on NPP. Moreover, these studies have been conducted at coarse resolution (1 km or larger), with research at fine resolution being scarce.

The Yangtze Delta, one of the most important agricultural and industrial regions in China, has the highest economic growth rate and population density. During the recent decades, the regional landscape was modified significantly by the rapid urbanization process. The urbanization process in metropolitan regions, such as Shanghai, received much attention while there were few studies on small or mid-size urban regions. Jiangyin County is representative of small urban regions that are widely distributed in the Yangtze Delta. The aim of this study was to assess the impact of urbanization processes on regional NPP in the Jiangyin region between 1991 and 2002.

2. Methods

2.1. Study area

Jiangyin is located between 31°41′24″N and 31°59′15″N latitude and between 119°59′E and 120°35′40″E longitude (Fig. 1). The total area is approximately 988 km^2 and its altitude ranges from 2 to 60 m above sea level. Located in the north subtropical zone, the characteristic annual temperature values for Jiangyin are 38.0 °C (average maximal), 15.1 °C (mean), and −6.0 °C (average minimal). Mean annual precipitation is 1040.7 mm and mean annual relative humidity is 80%. The main soil type is cultivated loessial soil. The dominant vegetation types in the Jiangyin region are cropland and forest-coniferous, deciduous, and ever-green broadleaved mixed forest. The dominant coniferous species are *Cunninghamia lanceolata Pinus massoniana* and *Pinus elliotii*, while broadleaved forests are dominated by *Liquidambar formosan* and *Cinnamomum camphora*.

2.2. Ecosystem model

Numerous models have been developed for NPP calculation. Progressing from statistical models (Leith, 1975) to recent process models (Chen et al., 1999; Daly et al., 2000; Keser et al., 2000; Kimball et al., 1997; Parton et al., 1993; Running and Coughlan, 1988; VEMAP, 1995), the modeling tools have become more sophisticated and their accuracy has been steadily improving. The Boreal Ecosystem Productivity Simulator (BEPS) was employed in this study. BEPS is a process-based biogeochemistry model developed on the basis of Forest-BGC (Running and Coughlan, 1988). It was refined by incorporating a more advanced photosynthesis model (Farquhar et al., 1980) with a new temporal and spatial scaling scheme (Chen et al., 1999), and an advanced canopy radiation transfer model representing canopy architecture of different vegetation types. BEPS calculates gross primary productivity (GPP), NPP and evapotranspiration (ET) with inputs of land cover, leaf area index (LAI), soil available water capacity (AWC), and daily meteorological data. BEPS has been applied in various regions including Canada, Japan, China, and East Asia (Liu et al., 1999; Matsushita et al., 2002, 2004) and its robustness has been repeatedly confirmed.

The BEPS modeling framework and the individual steps are shown in Fig. 2. The soil water balance content is first estimated by considering processes of rainfall, snowmelt, canopy interception, evapotranspiration and runoff using a soil "bucket" sub-model. Second, mesophyll conductance is calculated as a function of solar radiation, air temperature and leaf nitrogen concentration. The stomatal conductance is calculated as a function of radiation, air temperature, vapor pressure deficit (VPD), soil water content and available soil water capacity. Third, instantaneous gross photosynthesis is calculated using Farquhar's (1980) model:

$$W_c = V_m \frac{C_i - \Gamma}{C_i + K}, \tag{1a}$$

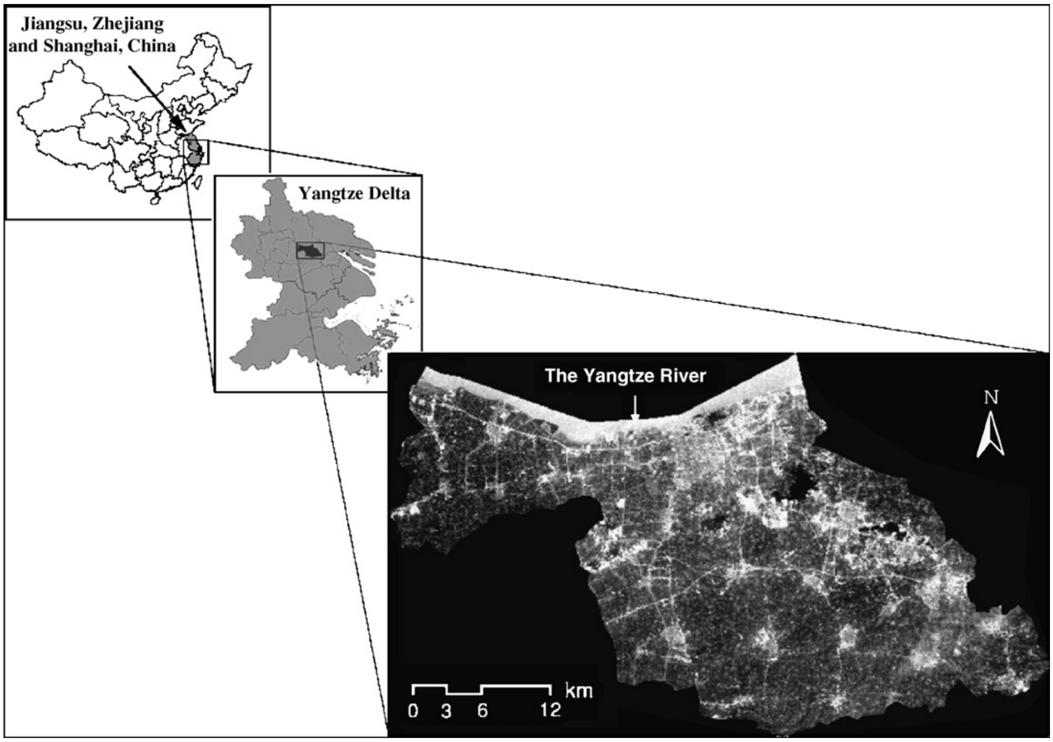

Fig. 1. Location of Jiangyin County, as seen from Landsat ETM+ band 3 image on October 1st, 2002.

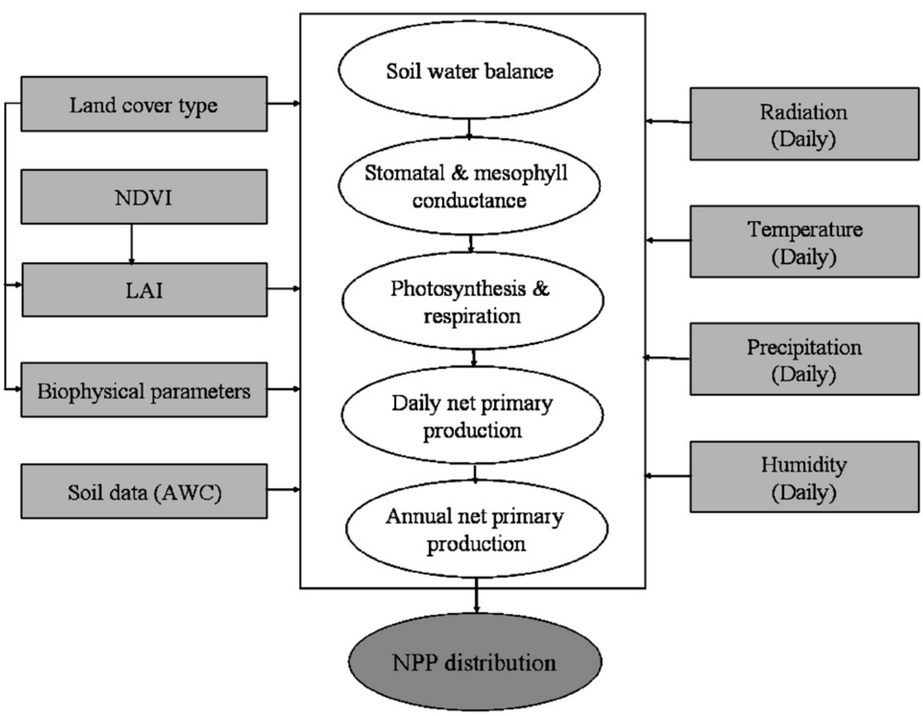

Fig. 2. Framework of BEPS model (Liu et al., 1997).

$$W_j = J\frac{C_i - \Gamma}{4.5\,C_i + 10.5\,\Gamma}, \tag{1b}$$

where W_c and W_j are Rubisco-limited and light-limited gross photosynthesis rates, V_m is the maximum carboxylation rate, J is the electron transport rate, C_i is the intercellular CO_2 concentration, Γ is the CO_2 compensation point without dark respiration, and K is a function of enzyme kinetics. To obtain net CO_2 assimilation rate (A), daytime leaf dark respiration (Rd) is subtracted from

Eq. (1a) and (1b):

$$A = \min(W_c, W_j)\text{-}Rd. \tag{2}$$

A_c and A_j correspond to W_c and W_j, respectively. At leaf level, daily average A is calculated through integration of photosynthetic rate and can be finally presented as Eq. (3) as the minimum of A_c and A_j:

$$A = \frac{1.27}{2(g_n - g_{min})}\left(\frac{a^{1/2}}{2}(g_n^2 - g_{min}^2) + c^{1/2}(g_n - g_{min}^2) - \frac{2ag_n + b}{4a}d + \frac{2ag_{min} + b}{4a}e^{1/2} + \frac{b^2 - 4ac}{8a^{3/2}}\ln\frac{2ag_n + b + 2a^{1/2}d}{2ag_{min} + b + 2a^{1/2}e}\right), \tag{3}$$

where g_n is the conductance at noon, and g_{min} is the minimum conductance before sunrise or after sunset. For A_c, $a = (K + Ca)^2$, $b = 2(2\Gamma + K - Ca)V_m + 2(C_a - K)Rd$ and $c = (Vm - Rd)^2$; for A_j, $a = (2.3\Gamma - Ca)^2$, $b = 0.4(4.3\Gamma - Ca)J + 2(Ca + 2.3\Gamma)Rd$, and $c = (0.2J - Rd)^2$. Ca is CO_2 concentration in the atmosphere. For both Ac and A_j, $d = (ag_n^2 + bg_n + c)^{1/2}$ and $e = (ag_{min}^2 + bg_{min} + c)^{1/2}$.

At canopy level, the total photosynthesis (A_{canopy}) for sunlit and shaded leaves is calculated separately:

$$A_{canopy} = A_{sun}\text{LAI}_{sun} + A_{shade}\text{LAI}_{shade}. \tag{4}$$

NPP is GPP minus maintenance respiration minus growth respiration. The maintenance respiration of stem, leaf and root is calculated separately from their respiration coefficients, biomass and temperature. The growth respiration is estimated to be 20% of GPP. Finally, annual NPP is obtained by summing daily NPP (Eq. (5)):

$$A_{NPP} = \sum_i (\text{GPP} - R_g - R_m), \tag{5}$$

where R_g and R_m are growth respiration and maintenance respiration, respectively.

2.3. Image pre-processing

For the study, we selected two cloud-free Landsat scenes of Path 119, Row 38. A TM image was acquired on July 4th, 1991 and an ETM+ image on October 1st, 2002. We used global positioning system (GPS) measurements to obtain locations of ground control points (GCPs). Thirty five evenly distributed GCPs were used to make geometric corrections of each scene, with a root mean square error (RMSE) of less than 0.5 pixel using a third-order polynomial. The images were then resampled to 30 m pixel size using the nearest-neighbor option. The images were georeferenced to the UTM zone 50, using WGS84 datum.

The Landsat data were transformed into radiance using gain and offset coefficients from the header file. A second simulation of the satellite signal in the solar spectrum (6S model) (Vermote et al., 1997) was then employed to make atmospheric corrections. The 6S options of continental airmass, mid-latitude summer and homogeneous targets were chosen, with atmospheric visibility set at 15 km. In this manner, land surface reflectance values were obtained for each image. Since the study area has an almost flat topography, no topographic correction was required.

2.4. Data preparation and NPP calculation

The remote sensing imagery was masked using the region boundary of Jiangyin County. A supervised classification approach was chosen for mapping the land cover using the maximum likelihood method. As demonstrated in previous studies, visual interpretation of Landsat imagery could be used as a useful tool in land cover mapping (Cohen et al., 1995; Jiang et al., 2004; Wilson and Sader, 2002; Zheng et al., 1997). Supervised classification results were therefore revised according to visual interpretation and ground survey. Finally, land cover maps for 1991 and 2002 were derived showing five land cover types: (1) residential area, (2) cropland, (3) coniferous forest, (4) broadleaved forest, and (5) wetland. Accuracy assessment was conducted using the ground truth data collected during field survey; the accuracy of both land cover maps exceeded 90% (91.5% for 1991 and 90.8% for 2002).

Leaf area index (LAI) is one of the most important inputs for many process models as well as BEPS, and remote sensing is the only way to obtain LAI distribution over large areas. We used the 2002 Landsat ETM+ surface reflectance image and ground based measurements data to retrieve spatial distribution of LAI. Homogeneous sites without obvious human disturbance were chosen for LAI measurements. At each 150 m × 150 m site, ten measurements were made and the mean value was taken as measured LAI. Forest LAI measurements were conducted using a digital camera with a fisheye lens and global positioning system (GPS) in June 2003. These ground LAI measurements and Landsat imagery were both acquired when the LAI of each vegetation type reached its maximum, thus minimizing the error introduced by differences in acquisition dates. The photos of vegetation canopies were imported to the software Gap Light Analyzer (GLA) v2.0 (Frazer et al., 1999) to calculate LAIs for forest sites. Crop LAI was measured with a SunScan canopy analysis system (Delta-T Devices, Cambridge, UK) (Potter et al., 1996). Linear regression was then computed between the measured LAI and NDVI for each vegetation type, with the following results (Y is LAI, X represents NDVI):

$$\text{Coniferous forest}: \quad Y_1 = 17.548 * X_1 - 6.853 \quad (R^2 = 0.57), \tag{6}$$

$$\text{Broadleaved forest}: \quad Y_2 = 20.381 * X_2 - 8.577 \quad (R^2 = 0.54), \tag{7}$$

$$\text{Cropland}: \quad Y_3 = 8.264 * X_3 + 0.273 \quad (R_2 = 0.61). \tag{8}$$

LAI changes with season but the method above could only be used to retrieve LAI distribution from a single-date. MODIS LAI products in 2002 and Global Land Cover 2000 data were therefore used to acquire LAI time-series. First, the LAI temporal curve during the year 2002 of all land cover types in Jiangyin region was produced. Based on Eq. (9), LAI during a year was reconstructed by matching MODIS seasonal pattern with the Landsat value. Fig. 3 shows a time series of retrieved broadleaved forest LAI in one pixel.

$$\text{LAI}_\text{S} = \text{LAI}_\text{C} \times \text{LAI}_\text{L}/\text{LAI}_\text{M}, \tag{9}$$

where LAI_S is the time series LAI to be reconstructed, LAI_C is the value on the MODIS LAI curve, and LAI_L and LAI_M are retrieved LAI values from Landsat imagery and MODIS at the closest dates, respectively.

The LAI distribution in 1991 was retrieved using the same algorithm because of lack of corresponding ground measurements. Based on the forest inventory data of 1991 and field survey data of 2003, we selected sites where no significant changes occurred in forest composition during the 11 years. Thus the LAI of these sites could have varied little between 1991 and 2002. Assuming further that the cropland LAI in the selected sites for ground measurements has not changed between 1991 and 2002 because the crop type was paddy in both of the years, the LAI distribution in 1991 was obtained for all vegetation types.

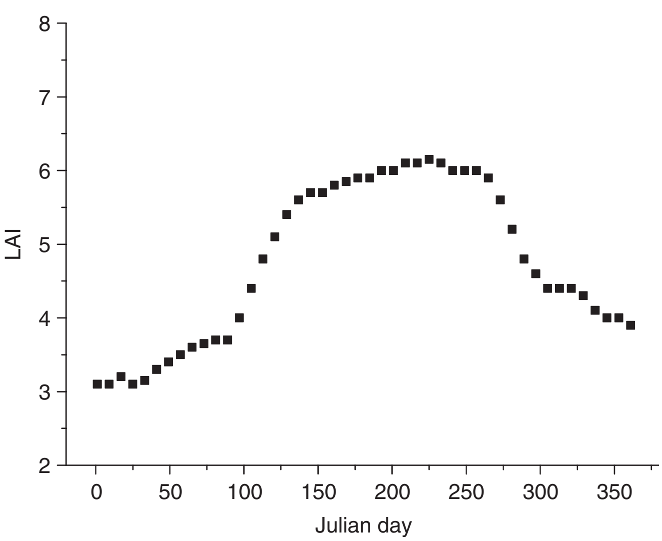

Fig. 3. Example of LAI variation in a pixel during the year 2002.

Daily meteorological data were collected at the Jiangyin climatic station. As information on available soil water capacity research is relatively scarce in China, the AWC value was set to 0.3 in view of soil homogeneity in Jiangyin (Mao and Wang, 1995; Zhou et al., 2003). Biological parameters of different ecosystems are crucial for most process models. In this study, the main biological parameters were taken from Matsushita et al. (2002) because of the similarity between the two study areas (Table 1).

3. Results and discussion

3.1. LUCC in urbanization process

Between 1991 and 2002, the residential area increased by 63.7% (to 114.0 km^2), thus occupying 11.5% of the land in Jiangyin region (Table 2). The residential distribution in the years 1991 and 2002 as well as expanded residential areas during the period are shown in Fig. 4. Many scattered small residential patches vanished, while large urban patches greatly expanded. The increased transportation network enhanced the connections among these urban patches. In contrast, the areas of cropland, forest and wetland all decreased. The residential area expanded mostly into former cropland. There was 155.7 km^2, or 23% of cropland transformed to residential areas. Urban expansion also had a substantial influence on forest ecosystems. Although only 4.8 km^2 of forest area was transformed to urban use, this represented 25.3% of the total forest area. In total, about 55% of forest was converted to cropland or residential areas. Basically, forest fragmentation is not reversible in Jiangyin (Table 2).

During the 11-year period, many small rural settlements were abandoned. With the rural population migrating to urban areas and the main urban patches growing, the intensity and frequency of human disturbance increased with time. The encroachment of urban sprawl on cropland

Table 1
Biological parameters and initial carbon content for various land covers in BEPS

	Unit	Broadleaved forest	Coniferous forest	Crop	References
Clump index	—	0.7	0.5	0.9	Chen (1996) and Chen and Cihlar (1995)
Maximum stomatal conductance (H_2O)	$m\,s^{-1}$	0.0045	0.00225	0.002	Hunt et al., (1996) and Matsushita et al. (2002)
Leaf respiration coefficient	$kg\,C\,day^{-1}\,kg^{-1}$	0.00398	0.00267	0.002	Foley (1994) and Matsushita et al. (2002)
Stem respiration coefficient	$kg\,C\,day^{-1}\,kg^{-1}$	0.00005	0.00005	0.00005	Foley (1994) and Matsushita et al. (2002)
Root respiration coefficient	$kg\,C\,day^{-1}\,kg^{-1}$	0.0002	0.0002	0.0002	Foley (1994) and Matsushita et al. (2002)
Leaf carbon content	$kg\,C\,m^{-2}$	0.3	0.5	0.1	Foley (1994) and Matsushita et al. (2002)
Stem carbon content	$kg\,C\,m^{-2}$	8	9.2	0.1	Foley (1994) and Matsushita et al. (2002)
Root carbon content	$kg\,C\,m^{-2}$	1.7	2.3	0.1	Foley (1994) and Matsushita et al. (2002)

Table 2
Land use and land cover change in Jiangyin County from 1991 to 2002 (unit: km^2)

	Residential	Wetland	Cropland	Forest
Area in 1991	179.0	112.5	677.6	18.9
Area in 2002	293.1	84.2	601.3	9.4
Changed area	114.0	−28.3	−76.3	−9.5
Amplitude (1991–2002) (%)	63.7	−25.2	−11.3	−50.3
Transitional area (1991–2002)				
Residential	122.6	0.8	55.3	0.2
Wetland	9.9	69.1	33.4	0.1
Cropland	155.7	14.1	507.3	0.5
Forest	4.8	0.1	5.4	8.6
Transitional probability (1991–2002) (%)				
Residential	68.5	0.5	30.9	0.1
Wetland	8.8	61.4	29.7	0.1
Cropland	23.0	2.1	74.8	0.1
Forest	25.3	0.7	28.6	45.4

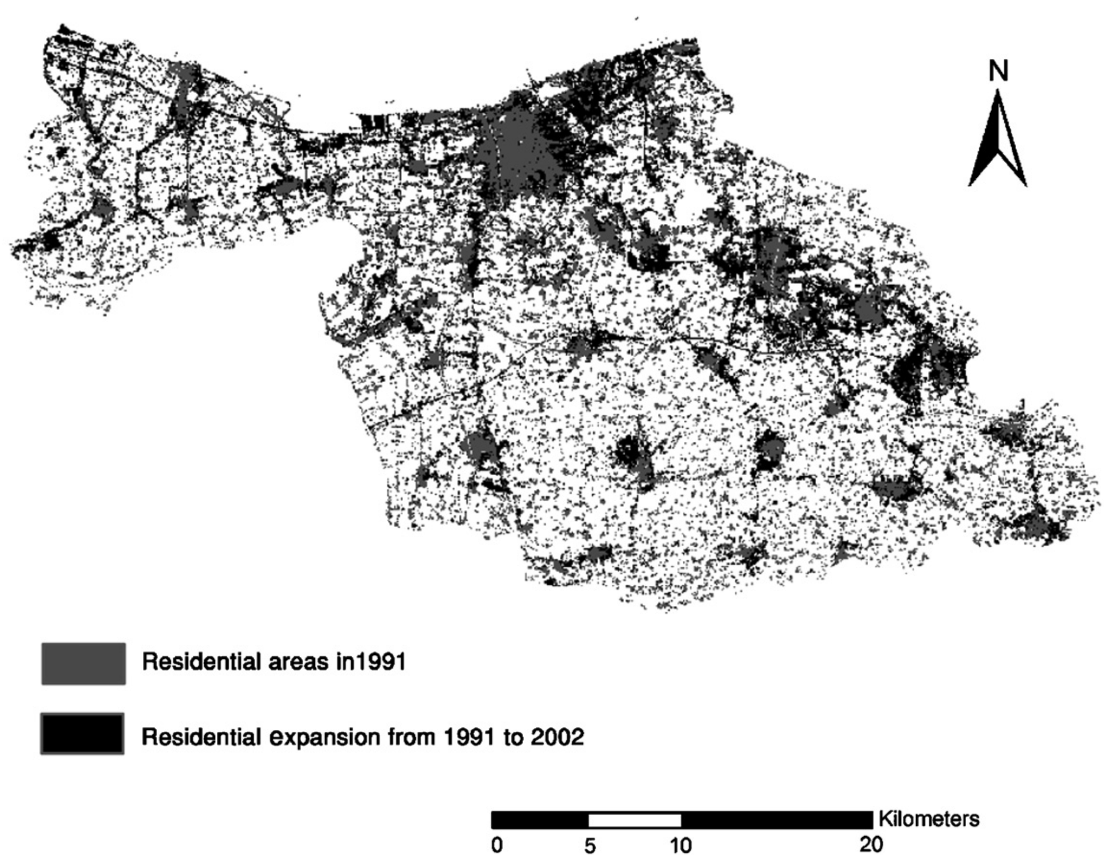

Fig. 4. Residential areas in 1991 and residential expansion from 1991 to 2002.

and forest in Jiangyin is consistent with land transformation undergoing urbanization worldwide (Thomlinson and Rivera, 2000).

The LUCC results show that urbanization was the most important landscape change in Jiangyin. Human activities modified about 29% of the land area in total, thus potentially influencing regional NPP in a significant way.

3.2. Urbanization effects on NPP

NPP distribution in 1991 and 2002 simulated by BEPS is shown in Fig. 5. Mean NPP of each vegetation type decreased during the 11-year period (Table 3). The largest NPP loss ($87\,g\,C\,m^{-2}\,yr^{-1}$) occurred in broadleaved forest. NPP loss in coniferous forest and cropland was 64 and 31 g

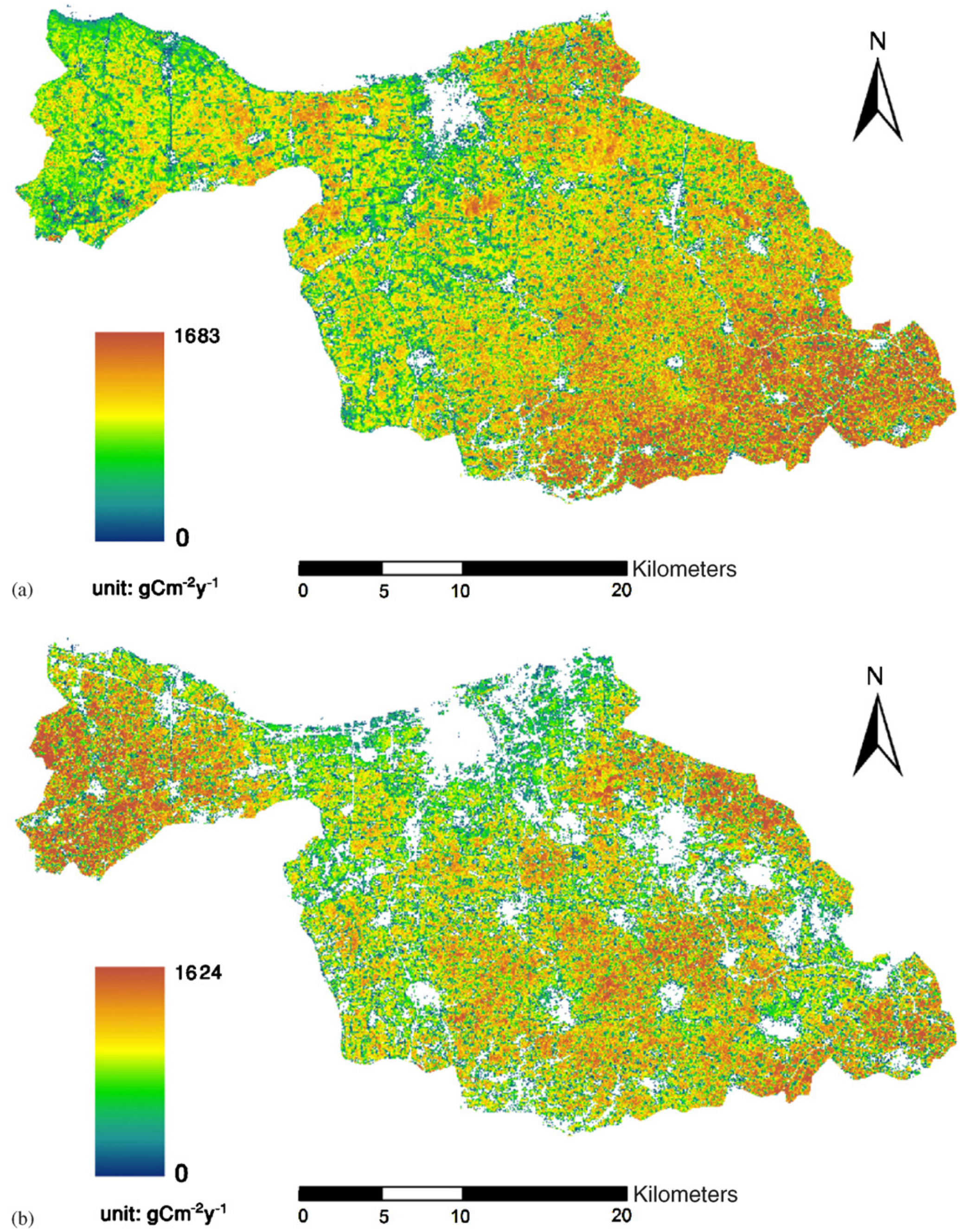

Fig. 5. NPP distribution in Jiangyin County in 1991 (a) and 2002 (b).

$C\,m^{-2}\,yr^{-1}$, respectively. The net primary production in Jiangyin region decreased from 808 to 691 Gg C between 1991 and 2002 ($1\,Gg = 10^9\,g$). Regional total primary production thus decreased by 117 $Gg\,C\,yr^{-1}$ or 14.5% of the net primary production in 1991.

During the 11 years between 1991 and 2002, mean NPP of the total area of Jiangyin region decreased from 818 to 699 $g\,C\,m^{-2}\,yr^{-1}$. Among all the land cover types, forest (including broadleaved and coniferous forest) NPP decreased about 13% while cropland NPP only decreased about 3%.

There are many factors which could influence the regional NPP, such as climate (solar radiation, temperature, humidity and precipitation), land use and land cover, soil type, leaf area index, species characteristics and human disturbance. As there was no obvious change in climatic factors in 1991 and 2002, the most important reasons for total NPP reduction were land cover transformation and human disturbance resulting from urbanization. The reduction in mean forest NPP was mainly caused by increasing human disturbance. In Jiangyin County, forest is mainly located on the rural hills and with intensified industrial and agricultural activities, forest fragmentation became severe. About 50.3% of the forest was destroyed and transformed to bare land or cropland. Between 1991

Table 3
Mean and total NPP in 1991 and 2002

	Cropland	Coniferous forest	Broadleaved forest	Total area
Mean NPP ($g\,C\,m^{-2}\,yr^{-1}$)				
1991	1168	782	995	818
2002	1137	718	908	699
Loss	31	64	87	119
Fraction (%)	2.7	8.2	8.7	14.5
Net primary production ($Gg\,C\,yr^{-1}$)				
1991	791	9	8	808
2002	684	4	3	691
Loss	107	5	5	117
Fraction (%)	13.5	55.6	62.5	14.5

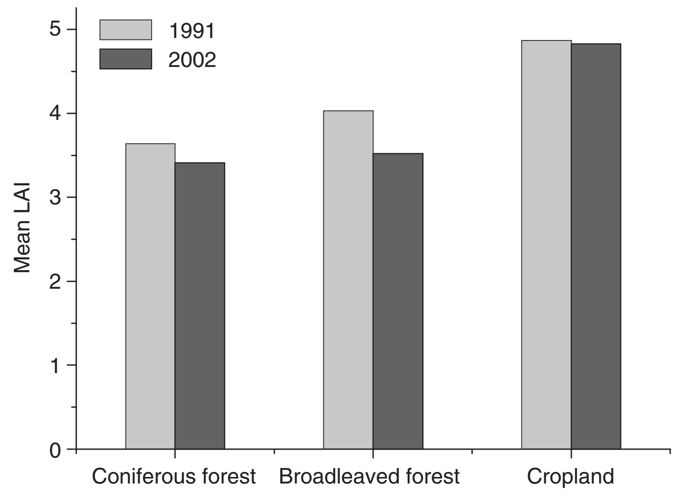

Fig. 6. Variation of mean LAI of each vegetation type.

and 2002, the population of Jiangyin increased by 5% and the GDP growth rate was nearly 14% per year. Disturbance frequency and intensity increased with the growth of population and economy. Various types of disturbance, including travel, logging and graveyard expansion, could change the composition and structure of forest communities. According to the forest inventory data and field survey, clearing of deciduous forest was very common during the 1990s in Jiangyin County. With increasing attention to environmental conservation by the government in recent years, ecological restoration was brought into effect in many areas. However, the young re-established forest has a lower LAI than the removed mature forest. The reduction of LAI caused by disturbance and changes in forest composition and structure was the most important reason for decreasing NPP per unit area. The mean LAI of broadleaved forest decreased 0.51, and that of coniferous forest decreased 0.33 (Fig. 6), while the mean LAI of cropland remained basically unchanged despite a slight decrease. Compared with forest, intensive management (fertilization, irrigation, etc.) could keep cropland NPP relatively stable.

In field measurements of NPP in the north subtropical zone (Liang and Hong, 1992; Feng et al., 1999), NPP of the overstory of deciduous and evergreen broadleaved mixed forest and coniferous forest was 608 and 400 $g\,C\,m^{-2}\,yr^{-1}$, respectively. Since those measurements did not include other layers of forest, the results underestimated the actual NPP. In the subtropical zone of East China, the mean NPP of evergreen broadleaved forest was 2073 $g\,C\,m^{-2}\,yr^{-1}$ (1508–2961 $g\,C\,m^{-2}\,yr^{-1}$) and that of coniferous forest was 1123 $g\,C\,m^{-2}\,yr^{-1}$ (996–1371 $g\,C\,m^{-2}\,yr^{-1}$). In general, mean forest NPP in subtropical zones is higher than in the northern subtropical zone (Feng et al., 1999). Our results were close to the measurements cited above, thus indicating that BEPS is a suitable model for subtropical ecosystems, even though it was originally developed for boreal ecosystems.

Our results show that urbanization decreased NPP in the Jiangyin County. NPP of forest decreased nearly 10% due to human disturbance. In the meantime, with the rapid development of industry and increasing demands for fossil fuel in Jiangyin County, CO_2 emission tended to increase due to the urbanization process at regional scale though the exact data for CO_2 emission was hard to get. Hence, the overall carbon release in the area increased in the 11-year period. A similar situation may well exist elsewhere in the Yangtze Delta and in other areas experiencing rapid urbanization (Milesi et al., 2003). Large areas of cropland were transformed by urban expansion, which reduced primary production by 15%. The reduction influenced the food supply for human beings (Imhoff et al., 2000), and the situation should be given greater attention, especially in developing countries with large population densities.

4. Conclusion

Urbanization makes a strong impact on the environment. Estimating the effects of urbanization on regional NPP has great importance for global carbon cycle studies. However, few studies have addressed this issue so far, and none of them was conducted at a high spatial resolution. A process model, BEPS, was used to assess the urbanization impact on regional NPP in a region with moderate size communities that has been undergoing rapid urbanization. Although initially developed for use in boreal ecosystems at continental scales, the model was found to be directly applicable to northern subtropical ecosystems, and to use with fine resolution remote sensing images.

During the past decade, land use and land covers changed greatly during the urbanization process in Jiangyin. Human settlements expanded in large areas, and meanwhile, the areas of forest and cropland shrunk. The transformation of cropland and forest to urban use was the major form of LUCC. Regional NPP was reduced by 14% due to urban sprawl and to an increasing frequency and intensity of human disturbances. As a result, urbanization produced negative impacts on carbon sequestration and food supply in the Jiangyin region.

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