Cities 31 (2013) 276–284

Contents lists available at SciVerse ScienceDirect

Cities

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

Impacts of land use/land cover change and socioeconomic development on regional ecosystem services: The case of fast-growing Hangzhou metropolitan area, China

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ARTICLE INFO

Article history:
Received 27 March 2012
Received in revised form 4 August 2012
Accepted 5 August 2012
Available online 29 August 2012

Keywords:
Land use/land cover (LULC) change
Ecosystem service value
Metropolitan area
Hangzhou
China

ABSTRACT

This study analyzes land use dynamics, spatiotemporal patterns of ecosystem service value (ESV), and the forces driving growth in the Hangzhou metropolitan area (HMA) in China. An integrated approach utilizing a Geographic Information System (GIS) and Remote Sensing (RS) was used to extract information on land use/land cover (LULC) change over the period of 1978–2008 from time-series Landsat MSS/TM/ETM+ imagery. We found that the areal extent of built-up land increased by 169.85%, while that of bare land increased by 83.70%. The outward expansion of built-up land and the net increase in bare land, both of which have a low ESV, indicate that human encroachment into surrounding natural and semi-natural ecosystems is resulting in decreased regional ecosystem service functions. Regional total GDP measured in constant value for the year 2000 increased by a factor of 31.71, and total population increased by 72.40% in 1978–2008. The resulting LULC change and socioeconomic development are likely responsible for the overall decline of 24.04% in regional ESV. It is projected that increasing land use demand will place heavy pressure on the natural and semi-natural ecosystems and impair the ecological functions that are necessary to support the human-dominated ecosystem. Therefore, sustainable development policies must address the impact of the loss of semi-natural and natural lands due to drastic urbanization.

Introduction

The growth of urban areas and the impact of human activities on ecosystems have been major issues of ecological interest. The impact of LULC change, both anthropogenic and natural, is well documented and raises concerns about the processes and functions of ecosystems (Chase, Pielke, Kittel, Nemani, & Running, 1999; Lambin et al., 2001). In the post-war era, population growth and economic expansion have been the primary drivers of LULC change worldwide, especially in developing countries that prioritize economic prosperity (Ingram, DeClerck, & del Rio, 2012; Li, Wang, Wang, Ma, & Zhang, 2009). Seventy percent of the world's largest cities can now be found in the developing world (Cohen, 2006). The rapid urbanization and pervasive LULC change that are occurring in fast-growing developing countries such as China, India, Pakistan, Turkey, and the countries of Latin America have been attracting increasing attention (Dewan & Yamaguchi, 2009; Geymen & Baz, 2008; Henrıquez, Azocar, & Romero, 2006; Kumar, Pathan, & Bhanderi, 2007; Liu, Liu, Zhuang, Zhang, & Deng, 2003; Lopez, Bocco, Mendoza, & Duhau, 2001).

Since 1978, China has enjoyed unprecedented economic growth and undergone remarkable social restructuring (Wei & Ye, 2009). This dramatic transition has led to accelerated urban expansion and has driven more people, especially those who have lost their land, to seek employment opportunities and residency in urban areas. The number of cities in China has rapidly increased from 193 in 1978 to 660 in 2008. Meanwhile, the total urban population grew considerably from 172.45 million to 606.67 million over the same period (China National Bureau of Statistics, 2009). In the past three decades, rapid economic and population growth have triggered these trends in the developing regional and international metropolitan areas of China. China's 20 fastest-growing metropolitan areas (including Beijing, Tianjin, Suzhou, Shanghai, Hangzhou, Guangzhou, and Shenzhen) are located primarily in the coastal region. These major metropolitan areas are the preferred destination for millions of domestic migrants and overseas investors and have been engines of China's economic growth (Chen, Zeng, & Xie, 2000; Ye & Xie, 2012). Unfortunately, only 26% of land in China is suitable for urban development (Qiu, 2007). Inevitably, during the unprecedented transition from a largely agricultural society to a

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0264-2751/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.cities.2012.08.003

modernized and industrialized society, huge areas of arable land, forest, and grassland, as well as numerous bodies of water, have been used in new ways to meet strong demand stemming from urbanization and industrial development. With rapid development of the economy and urban expansion, these areas have suffered environmental pollution, ecological deterioration, and economic loss (Su, Jiang, Zhang, & Zhang, 2011). Given the important role of these metropolitan areas in China's economy, there is an urgent need to address these emerging environmental challenges and develop policies for sustainable development.

However, in planning for sustainability, we need to move beyond city limits and consider the entirety of the human-dominated system, which depends on natural ecosystem services. These services refer to vital benefits from ecosystem functions that underlie the foundation of human society (Bolund & Hunhammar, 1999; Burkhard, Petrosillo, & Costanza, 2010; Costanza et al., 1997; Daily, 1997; de Groot, Alkemade, Braat, Hein, & Willemen, 2010; Escobedo, Kroeger, and Wagner, 2011; Fisher, Turner, & Morling, 2009; Jim & Chen, 2009; Matthew, Troy, & Costanza, 2004; Sohngen & Brown, 2006; Vejre, Jensen, & Thorsen, 2010; Vihervaara, Kumpula, Tanskanen, & Burkhard, 2010). Scholarly research also included new explorations in both concepts and techniques of ecosystem services valuation (ESV) (Bastian, Haase, & Grunewald, 2011; Martín-López, García-Llorente, Palomo, & Montes, 2011; Olewiler, 2006; Raymond et al., 2009; Scolozzi, Morri, & Santolini, 2011; Sherrouse, Clement, & Semmens, 2011). This emerging literature offers a new perspective for better understanding of the value of our survival environment and the roots of human–environment conflicts (Atkins, Burdon, Elliott, & Gregory, 2011; Barral & Maceira, 2011; Brent et al., 2009; Frank, Fürst, Koschke, & Makeschin, 2011; Kroll, Müller, Haase, & Fohrer, 2012; Metzger, Rounsevell, Acosta-Michlik, Leemans, & Schroter, 2006; Shi, Cui, Yin, & Liu, 2010; Swallow et al., 2009; Swetnam et al., 2011). A number of recent case studies also focus on China (Cheng, Yang, Zhao, & Wu, 2009; Jim & Chen, 2009; Li, Li, & Qian, 2010; Liu, Li, & Zhang, 2012; Shi et al., 2010; Su, Xiao, Jiang, & Zhang, 2012; Yang, Li, Wang, & Hu, 2011; Zhao et al., 2004), which has witnessed an impressive rate of urban growth during the last three decades. Despite this analytical progress, however, due to constraints inherent in the methods and techniques of ESV, it remains a difficult task to quantitatively examine the relationship between changes in ESV and the sustainability of the human-dominated ecosystem. It is especially difficult to characterize the relationship between urban growth patterns, changes in ESV, and the consequent loss of ecological capacity supporting human-dominated ecosystem.

The present study focuses on the Hangzhou metropolitan area (HMA), which is the second largest metropolis in the Yangtze River Basin (Li & Li, 2005). Hangzhou is well known as an international garden city and has a recorded history dating back 2200 years (The municipal government of Hangzhou, 2007). Due to its advantageous location, favorable economic status, and international fame, this area serves as a useful case study. Comprehensive studies on long-term variation in ESV in response to LULC change and socioeconomic change are very scarce in this area. The objectives of this paper are the following: (1) to characterize land use dynamics and patterns in LULC change across various stages of urbanization in the HMA in the context of globalization and economic reform; (2) to depict spatiotemporal patterns of ESV in response to LULC change using remote sensing and GIS techniques; and (3) to quantitatively examine the relationships between LULC change, socioeconomic change, and regional ESV. The dynamic mosaic of landscape patterns in metropolitan China has raised many interesting issues for researchers, igniting the imaginations of environmental scientists, geographers, and public policy scholars. As a whole, we aim to uncover policy implications for the sustainable management of land development at the metropolitan level. We hope this case study will provide useful information for other cities in the Yangtze River Basin and in other similar locales.

Methodology

Study area

The HMA is situated between latitudes 29°50′N and 30°32′N and longitudes 119°41′E and 120°43′E (Fig. 1). It covers an area of approximately 3319.7 km^2, with a total population of 4.24 million. The administrative area of the HMA consists of Hangzhou city, which is the capital city of Zhejiang Province, and two municipalities. The city proper consists of six administrative wards: Shangchen/SC district, Xiacheng/XC district, Jianggan/JG district, Xihu/XH district, Bingjiang/BJ district, and Gongshu/GS district. The two municipalities are Yuhang/YH district (formerly Yuhang County) and Xiaoshan/XS district (formerly Xiaoshan County). The local GDP per capita in 2008 was approximately 77,230 RMB Yuan (equivalent to 11,192 US dollars) (Hangzhou municipal Bureau of Statistics, 2009), which is well above the national average (approximately 3315 US dollars).

Satellite data pre-processing and land use classification

In this study, time series of LULC data sets were produced from multi-spectral Landsat MSS/TM/ETM+ imagery, which were acquired on five separate dates: July 5, 1978, August 4, 1984, July 23, 1991, October 11, 2000, and April 24, 2008. All of the images were clear and nearly free of clouds. Prior to interpretation, atmospheric correction and geometrical rectification were performed. The image processing and data manipulation processes were conducted using algorithms supplied by the GEOSTAR 3.0® image processing software. ESRI ARCGIS 10.0® was used for spatial analyses. Based on the land use classification system created by the China National Committee of Agricultural Divisions (1984), eight land use categories were utilized in this study, including built-up land (consisting of urban area and rural settlements), cropland, fallow land, forest, shrub, water bodies (mainly rivers, channels, ponds, and reservoirs), tidal land, and bare land. The overall accuracy of LULC maps over the study period was determined to range from 80.70% to 88.56% with an average of 84.82%, and the Kappa statistic ranged from 0.776 to 0.852 with an average of 0.816. This met the recommended value suggested by Jessen, Frans, and Wel (1994). Thus, these data were available for further study. Furthermore, a cross-tabulation detection method was employed to perform change detection of LULC. The land use change matrix which showed quantitative data of the overall LULC changes between 1978 and 2008 in the study area was produced. Based on the main types of gains and losses in each category shown by the change matrix, land use transfer images and land use transfer matrix for each category were also produced.

Computation of ESV and ratio of ESV to GDP on regional level

Ecosystems provide many vital services, and the importance of ecosystem services can be measured using monetary valuations techniques (Tietenberg, 1992). There are several techniques for the monetary valuation of ESV, including the market-based approach (such as replacement/restoration cost/RC or production function analysis/PF) (Ellis & Fisher, 1987), the surrogate market approach (such as travel cost method/TCM and hedonic pricing/HP), and the simulated market approach (such as contingent valuation/CV) (Garrod & Willis, 1999). In this study, Xie, Lu, Leng, Zhen, and Li's (2003) method for valuing ecosystem services was adopted for the analysis of ESV in the HMA. Based on Costanza et al.'s

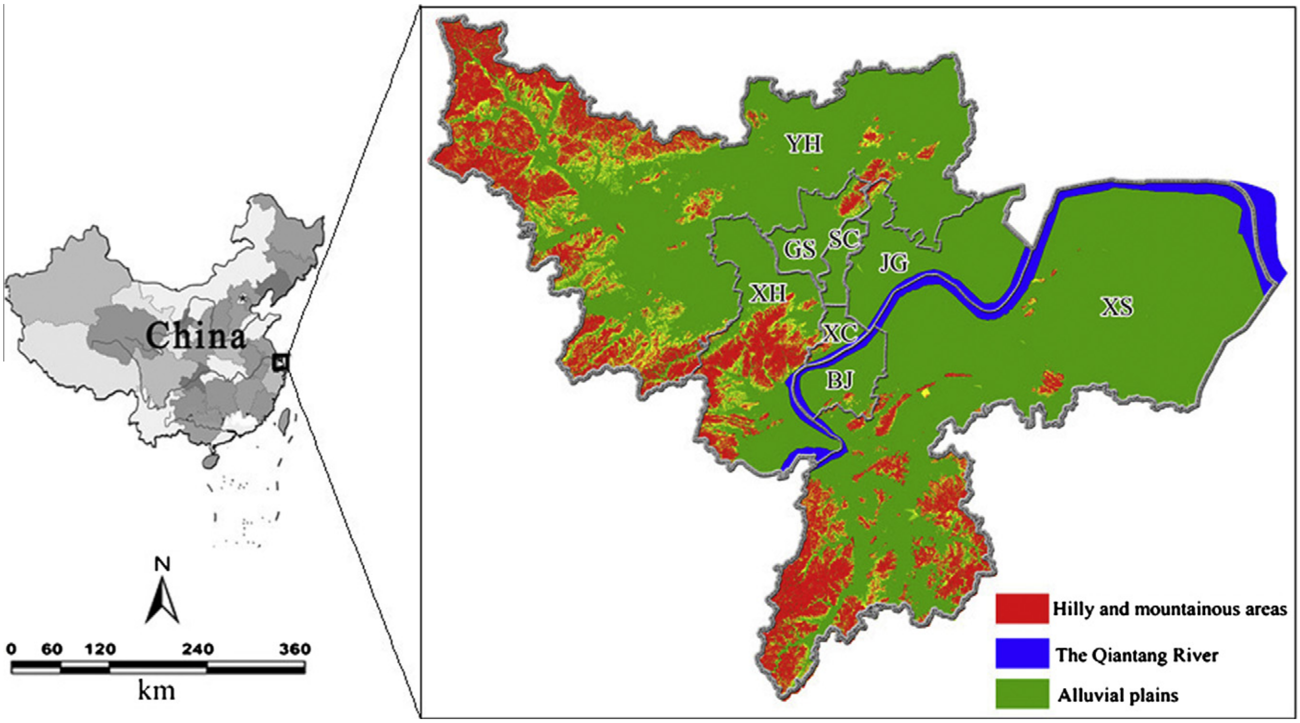

Fig. 1. Location of the study area.

pioneering work (1997), which used RC to derive economic values for the ecosystem services of global biomes, Xie et al. (2003) developed an enhanced method for valuing China's terrestrial ecosystem services by surveying 200 Chinese ecologists. Compared to Costanza et al.'s method, Xie et al.'s method is considered more practicable and has thus been widely applied in valuing China's ecosystem services (Cheng et al., 2009; Li et al., 2010; Liu, Li, & Zhang, 2012).

An annual average ecosystem service value per unit of area (RMB Yuan/ha) was assigned for each land use category in this study area (Table 1).

Thereafter, the estimated ESV across different years in the HMA was computed as follows:

$$\mathrm{ESV} = \sum_{i=1}^{m}\sum_{j=1}^{n} A_i \times VC_{ij} \tag{1}$$

where A_i is the area (ha) of land cover for type i, VC_{ij} is the value coefficient of ecosystem service function for type j (RMB Yuan/ha) combined with land cover type i. The estimated ESV in 2000 was set as the baseline and ESVs across different years were computed with the value coefficient in 2000. Thus, all the ESVs are comparable across time.

Furthermore, to depict variation of ESV in response to socioeconomic drivers, ratios of ESV to GDP($Ratio\_E/G$) on regional level across different years were computed as follows:

$$Ratio\_E/G_{1978} = \frac{\mathrm{ESV}_{1978}}{\mathrm{GDP}_{1978} \times AC_{1978\to 2000}} \tag{2}$$

$$Ratio\_E/G_{1984} = \frac{\mathrm{ESV}_{1984}}{\mathrm{GDP}_{1978} \times AC_{1984\to 2000}} \tag{3}$$

$$Ratio\_E/G_{1991} = \frac{\mathrm{ESV}_{1991}}{\mathrm{GDP}_{1978} \times AC_{1991\to 2000}} \tag{4}$$

$$Ratio\_E/G_{2000} = \frac{\mathrm{ESV}_{2000}}{\mathrm{GDP}_{2000}} \tag{5}$$

$$Ratio\_E/G_{2008} = \frac{\mathrm{ESV}_{2008}}{\mathrm{GDP}_{2008} \times AC_{2008\to 2000}} \tag{6}$$

where AC is the adjusted coefficient of constant price for regional GDP, accounting for variation in prices due to inflation. Similarly, the GDP in 2000 was set as the baseline. To adjust all the values across different years to constant year-2000 values, constant values in 1970, 1980, 1990, 2000, and 2005 were calculated (National

Table 1
Annual average ESV of unit area of different land use categories (RMB Yuan/ha).

	Forest	Shrub	Cropland	Water	Fallow land	Bare land	Tidal land	Built-up land
Gas regulation	3097.0	1769.7	442.4	0.0	294.9	0.0	0.0	0.0
Climate regulation	2389.1	1588.3	787.5	407.0	525.0	0.0	203.5	0.0
Water purification and provision	2831.5	1681.2	530.9	18033.2	353.9	26.5	9029.9	0.0
Soil protection	3450.9	2371.4	1291.9	8.8	861.3	17.7	13.3	0.0
Waste purification	1159.2	1287.2	1451.2	16086.6	967.5	8.8	8047.7	0.0
Biodiversity protection	2884.6	1756.4	628.2	2203.3	418.8	300.8	1252.1	0.0
Food production	88.5	177.0	884.9	88.5	589.9	8.8	48.7	0.0
Raw material	2300.6	1194.6	88.5	8.8	59.0	0.0	4.4	0.0
Recreation and culture	1132.6	570.7	8.8	3840.2	5.9	8.8	1924.5	0.0
Sum	19334.0	12396.5	6114.3	40676.4	4076.2	371.4	20523.9	0.0

Bureau of Statistics of China, 2009). The values of *AC* across different years are as follows:

$$AC_{1978\to2000} = 3.68, \quad AC_{1984\to2000} = 3.32, \quad AC_{1991\to2000} = 1.98, \text{ and } AC_{2008\to2000} = 0.71.$$

Statistical analysis

To detect the overall variability of change per LUC during 1978–2008, one way analysis of variance (ANOVA) was employed. Furthermore, to quantitatively examine the relationship between LULC change, variation in ESV, and socioeconomic change, and therefore provide further information for this study, statistical analyses were performed using the commercial DPS© 12.5 statistical package (Tang, 2010). After carefully checking the significance levels for the overall distribution and interaction effects of the variables, it was determined that neither linear nor multivariate regression models were appropriate. Instead, nonlinear regression models were adopted.

Results

Land use dynamics and land cover change

Fig. 2 shows general trends of land use dynamics and land cover change for the HMA in 1978–2008. According to the result of one-way ANOVA, areas in land cover types varied significantly across different years ($F_{7,32} = 23.44$, $P < 0.01$). Furthermore, Fig. 3 shows the overall variability of change per land cover type over the study period. It can be seen that land cover category changes in areas of forest, water bodies, bare land, and tidal land were relatively less frequent than those in areas of cropland, fallow land, and built-up land. Cropland decreased very little from 1978 to 1984 and increased substantially from 1984 to 1991 and from 1991 to 2000; however, remarkable decline in cropland was observed from 2000 to 2008, implying loss of cropland under pressure from an increase in built-up land, especially urban built-up land. The net decrease in shrub and net increase in built-up land were observed across different years, indicating gains and losses of land cover types among cropland, fallow land, and built-up land.

Table 2 shows the overall trend among different land cover types over the study period using a land use conversion matrix. In 1978, cropland, forest, and shrub were the dominant land cover types in the study area, accounting for 73.5% of the land cover category. In 2008, cropland was still the largest land cover category, followed by forest and built-up land. Over the past three decades, the built-up land has grown by 54,250 ha, while bare land has grown by 19,550 ha. In contrast, shrub has decreased by 56,760 ha, followed by water, cropland, and fallow land, which decreased by 5900 ha, 5170 ha, and 4280 ha, respectively. Forests decreased by 2330 ha, with a relatively low rate of loss. According to the land use conversion matrix, from 1978 to 2008, there was a substantial increase in built-up land over the other land cover types; remarkably, this growth exceeded the amount of land converted from built-up land to other land cover types. As shown in Fig. 4, over the period of the study, the loss of cropland and shrub accounted for 34.7% and 24.4% of newly emerging built-up land, respectively, followed by forest (9.9%), water (7.1%), and fallow land (4.2%). Thus, driven by robust socioeconomic factors, the ongoing increase in built-up land with lower ESV is responsible for a remarkable decline in total ESV. Approximately 80.37% of the newly emerging built-up land was converted from other land cover types. Another significant change was an increase in bare land. During the same period, bare land increased by 83.7%. Cropland, shrub, forest, and built-up land accounted for 29.4%, 31.2%, 15.2%, and 9.5% of the net increase in bare land, respectively. In the HMA, bare land was mainly created by new quarries, mining pits, abandoned croplands enclosed for construction, and the demolition of buildings under the pressure of land development.

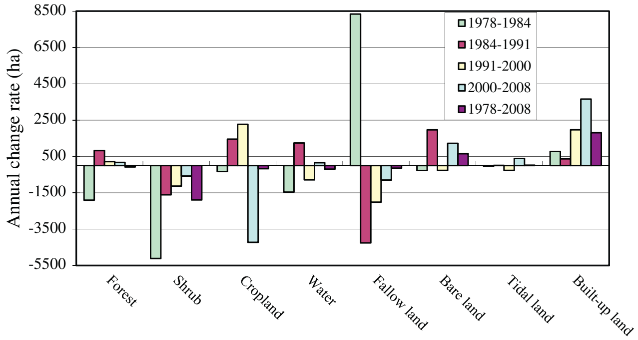

Fig. 2. Annual change rates of land cover types from 1978 to 2008.

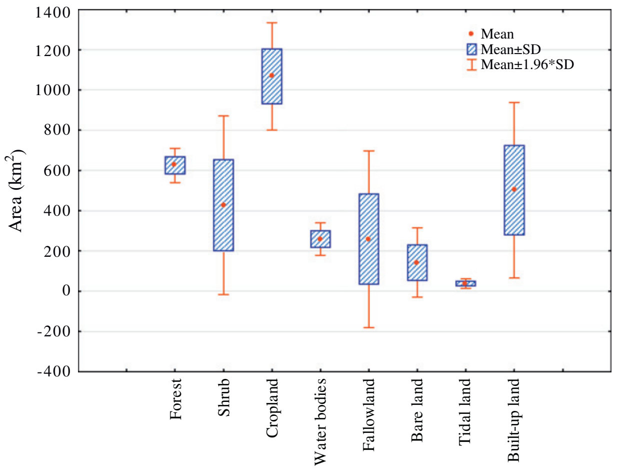

Fig. 3. Box and Whisker plot of area of land cover types from 1978 to 2008.

Overall trends in the ESV of ecosystem service function types

Table 3 shows overall trends in the ESV of ecosystem service function types for the study area from 1978 to 2008. Water supply, waste treatment, soil formation and retention, biodiversity protection, climate regulation, and gas regulation are the dominant ecosystem service function types. They accounted for 85.2% of total ESV on average, and the relative importance of each category remained the same over the study period. However, it is obvious that the ESV of all the ecosystem service functions decreased slowly but substantially over time. The sharp decline in total ESV between 1978 and 1984 is due to major changes in agriculture, which resulted in large areas of fallow land being created, which led to a significant decline in total ESV. The rebounding trend in total ESV in 1991 and substantial decline in 2000 and 2008 may be attributed to a loss of semi-natural land cover types, especially areas of shrub and cropland, due to accelerated urban expansion.

Spatiotemporal patterns of ESV

Table 4 shows temporal patterns of ESV associated with different land cover types. The ESV of forests accounts for 32.0% of the total ESV on average, followed by those of bodies of water (26.3%), cropland (18.0%), and shrub (13.7%). In summary, each of

Table 2
Land use conversion matrix from 1978 to 2008 (in km^2).

	Forest	Shrub	Cropland	Water	Fallow land	Bare land	Tidal land	Built-up land	Sum_1978
Forest	361.4	32.5	123.9	17.4	9.4	39.4	2.2	85.2	671.3
Shrub	139.6	102.1	219.5	17.6	16.1	80.7	4.3	210.3	790.2
Cropland	109.0	40.6	421.1	24.1	30.6	75.9	7.5	299.4	1008.2
Water	3.5	2.1	51.6	138.8	5.4	15.5	24.8	61.5	303.2
Fallow land	5.4	7.3	42.1	14.6	5.2	10.1	1.3	36.3	122.3
Bare land	11.7	20.6	8.0	1.4	1.1	10.0	0.2	10.0	63.0
Tidal land	0.4	0.1	9.4	13.2	1.5	2.3	2.0	13.2	42.1
Built-up	17.1	17.3	80.9	17.1	10.2	24.6	6.2	146.0	319.4
Sum_2008	648.0	222.6	956.5	244.2	79.5	258.5	48.5	861.9	3319.7

Note: The rows and columns contain data of 1978 and 2008 respectively.

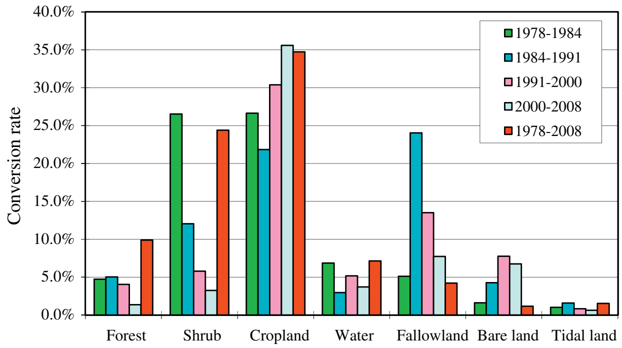

Fig. 4. Conversion rates of other land cover types to built-up land from 1978 to 2008.

these four land cover types has dominated as a land cover category in different years. Their ESV accounts for 90.0% of the total ESV on average, although the share of land occupied by shrub has decreased by 15.1% over the study period.

Table 4 and Fig. 5 show the spatial patterns of ESV in the study area from 1978 to 2008. It is clear that the eastern, northern, southern, southwestern, and northwestern parts of the study area are land use types with high or higher total ESVs across the study period. Forests have the highest ESV and are located in the southern, southwestern, and northwestern hilly and mountainous areas. Bodies of water are the land cover type with the second highest ESV in terms of their ESV coefficient, but their proportion of total land cover is small. Tidal land also has a very high ESV coefficient but a very small proportion of total land cover. A remarkable decline in water bodies and tidal land was caused by the reclamation of enclosed water bodies and tidal land for emerging cropland in the eastern portion of the study area in 1984 and 2008. Inevitably, this change resulted in a significant decline in the total ESV of bodies of water and tidal land. However, the newly emerging fishponds along the eastern Hangzhou Bay offset the loss in ESV from bodies of water. Shrub in the southern, southwestern, and northwestern hilly and mountainous parts of the study area were the land cover type with the third largest ESV, but shrubs were replaced by cropland as the land cover type with the third largest ESV due to substantial loss of shrubs under pressure from land

Table 3
Changes in ESV of ecosystem service functions of the study area from 1978 to 2008.

Ecosystem service functions	Year				
	1978	1984	1991	2000	2008
Gas regulation	396.0 (9.3%)	323.6 (9.1%)	327.6 (9.2%)	304.4 (9.0%)	284.2 (8.8%)
Climate regulation	384.9 (9.0%)	336.2 (9.5%)	330.7 (9.2%)	311.6 (9.2%)	279.5 (8.6%)
Water supply	965.8 (22.6%)	743.1 (21.0%)	769.3 (21.5%)	731.4 (21.6%)	758.6 (23.4%)
Soil formation and retention	560.3 (13.1%)	498.6 (14.1%)	488.8 (13.7%)	459.6 (13.6%)	405.8 (12.5%)
Waste treatment	859.4 (20.1%)	721.4 (20.4%)	736.5 (20.6%)	693.4 (20.5%)	680.4 (21.0%)
Biodiversity protection	474.9 (11.1%)	392.6 (11.1%)	395.7 (11.1%)	374.1 (11.1%)	356.3 (11.0%)
Food supply	119.3 (2.8%)	146.8 (4.1%)	143.3 (4.0%)	133.6 (4.0%)	100.5 (3.1%)
Raw material	258.8 (6.1%)	199.2 (5.6%)	198.8 (5.6%)	190.3 (5.6%)	184.7 (5.7%)
Recreation and culture	246.7 (5.8%)	182.6 (5.2%)	189.1 (5.3%)	180.9 (5.4%)	190.3 (5.9%)
Sum	4266.1 (100.0%)	3544.1 (100.0%)	3869.1 (100.0%)	3731.2 (100.0%)	3508.5 (100.0%)

Note: Shares of ESV for ecosystem service functions were parenthesized.

Table 4
Temporal patterns of ESV of land cover types (million RMB Yuan).

Land cover types	1978	1984	1991	2000	2008
Forest	1298.1 (30.4%)	1076.9 (30.4%)	1188.5 (30.7%)	1226.2 (32.9%)	1252.8 (35.7%)
Shrub	979.6 (23.0%)	598.9 (16.9%)	459.2 (11.9%)	333.2 (8.9%)	275.9 (7.9%)
Cropland	616.6 (14.5%)	604.3 (17.1%)	791.6 (20.5%)	791.6 (21.2%)	584.8 (16.7%)
Water body	1233.3 (28.9%)	877.0 (24.7%)	942.5 (24.4%)	942.5 (25.3%)	993.3 (28.3%)
Fallow land	49.8 (1.2%)	302.2 (8.5%)	395.8 (10.2%)	395.8 (10.6%)	292.4 (8.3%)
Bare land	2.3 (0.1%)	1.7 (0.0%)	6.8 (0.2%)	6.0 (0.2%)	9.6 (0.3%)
Tidal land	86.4 (2.0%)	83.1 (2.3%)	84.8 (2.2%)	35.9 (1.0%)	99.5 (2.8%)
Built-up land	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)	0.0 (0.0%)
Sum	4266.1 (100.0%)	3544.1 (100.0%)	3869.1 (100.0%)	3731.2 (100.0%)	3508.5 (100.0%)

Note: Shares of ESV for land cover types were parenthesized.

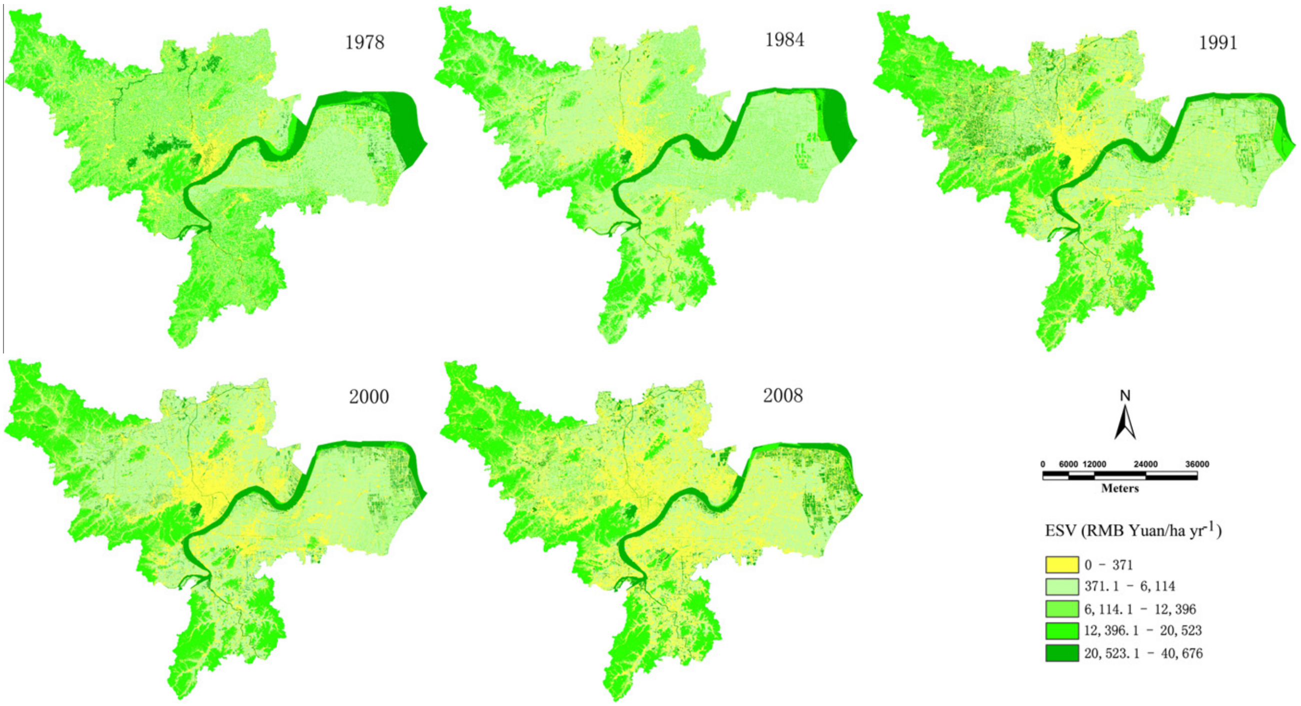

Fig. 5. Spatial patterns of areal ESV (RMB Yuan/ha year^{-1}) in the study area from 1978 to 2008.

development. Cropland located mainly in the northern, southern, and eastern alluvial plains is the dominant land cover type with the highest ESV due to its large area.

Variation of ESV in response to LULC change and socioeconomic drivers

Fig. 6 shows a negative non-linear relationship between GDP *per capita* and ESV *per capita*. Local GDP *per capita* in constant year-2000 prices increased by a factor of 24.3, from 2696.8 RMB Yuan in 1978 to 68239.7 RMB Yuan in 2008. At the same time, local ESV *per capita* decreased by 48.2%, from 1473.9 RMB Yuan in 1978 to 763.7 RMB Yuan in 2008. Furthermore, Fig. 7 shows an exponential decline in the ratio of total ESV to total GDP from 1978 to 2008. Herein, both Figs. 6 and 7 indicate that rapid economic growth had a substantial negative impact on regional ecosystem services. Similar to Fig. 5, Figs. 8–11 show the ongoing trend of decline in total ESV and ESV *per capita* with substantial demographic growth and expansion of built-up land and bare land.

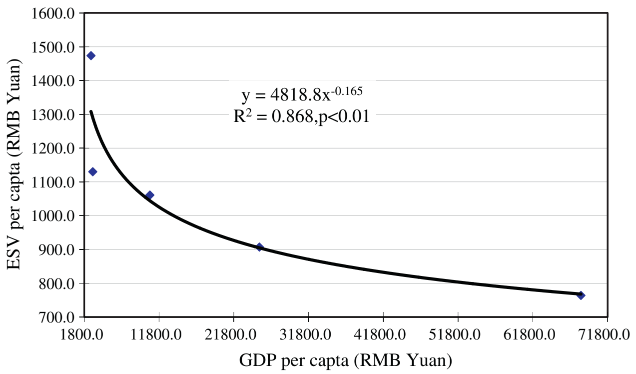

Fig. 6. Relation between GDP per capita and ESV per capita from 1978 to 2008.

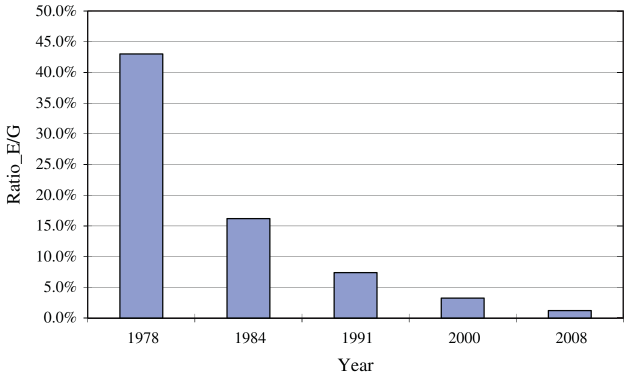

Fig. 7. Changes in the ratio of TESV to TGDP from 1978 to 2008. *Note*: TESV and TGDP mean total ESV and total GDP, respectively.

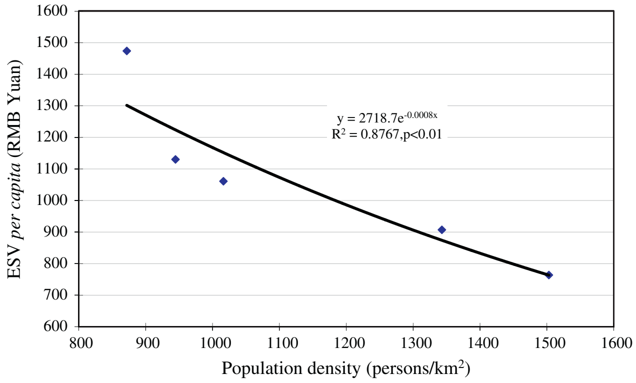

Fig. 8. Relationship between regional population density and ESV per capita from 1978 to 2008.

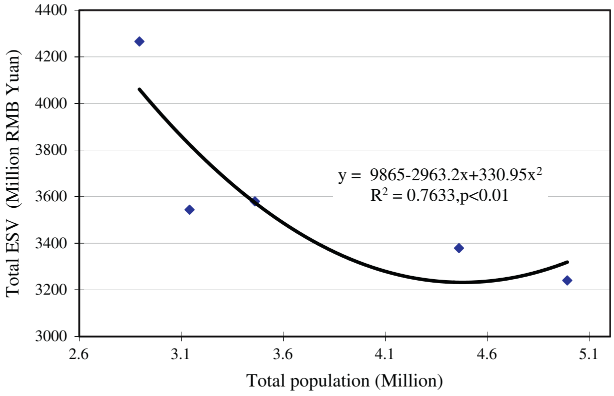

Fig. 9. Relationship between regional total population and total ESV from 1978 to 2008.

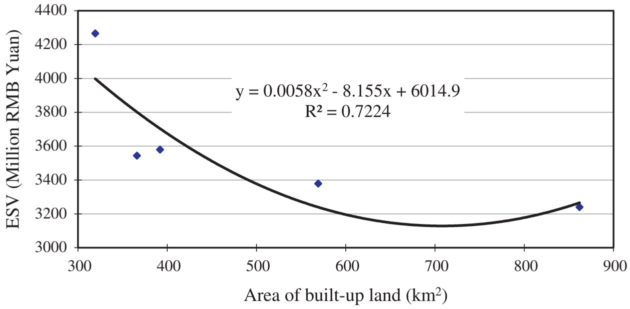

Fig. 10. Relationship between area of built-up land and ESV from 1978 to 2008.

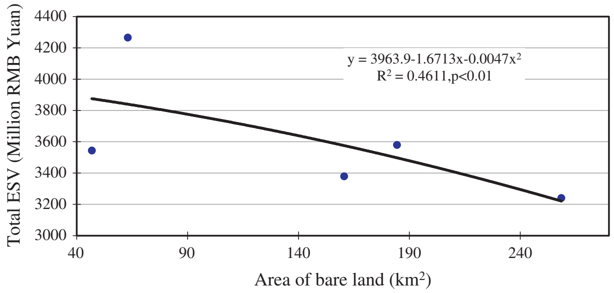

Fig. 11. Relationship between area of bare land and ESV from 1978 to 2008.

Table 5 shows annual change rates of regional total ESV, GDP, built-up land, and population in the study area from 1978 to 2008. For ESV, the change rate is −16.92% in the period 1978–1984. As previously mentioned, this change can be attributed to changes in the cultivation structure, which produced large areas of fallow land and caused a decline in regional total ESV. During the period 1984–1991, regional total ESV rebounded slightly when a small proportion of fallow land was converted to vegetated land, such as cropland and shrub, with higher ESV coefficients. However, negative annual change rates in ESV were observed during the periods 1991–2000 and 2000–2008. Furthermore, high economic growth, increases in built-up land, and increases in total population during the periods 1991–2000 and 2000–2008 make it clear that substantial economic growth, population growth, and an increase in built-up land and bare land have negative impacts on regional total ESV. To sum up, regional total GDP measured in constant year-2000 prices increased by a factor of 31.71 from 1978 to 2008, indicating exponential growth in the local economy. The total population, proportion of built-up land, and proportion of bare land increased by 72.40%, 169.85%, and 83.70%, respectively. LULC change, characterized by increase in built-up land, and socioeconomic development, characterized by growth in regional total GDP and population, are likely responsible for an overall decline of 24.04% in regional ESV.

Discussion

China's dramatic urban growth and changing environmental dynamics since the reform have generated many intriguing issues and challenges for scholarly research and policy-making (Liu, Song, & Arp, 2012; Wei & Li, 2002; Wu & Yeh, 1997). Historically and politically, Chinese cities have developed into modern metropolitan areas much differently than western countries and other developing countries (Gao, Zhou, & Xu, 2010; Wang, 1999). In China, private land ownership is prohibited and the government supervises the allocation and development of land resources. Therefore, the government plays the key role in guiding urban planning and regional development and in ensuring an orderly transition from the old planned economy to the current market-oriented economy. With growing public awareness of sustainability issues with regard to the environment, society, and the economy, any government plan should maximize the benefit of land use and minimize potential risks, effectively balancing conflicts between land use and environmental deterioration, establishing necessary urban infrastructure and providing services (Cao, Huang, Wang, & Lin, 2011). The importance of ESV as a useful tool in enhancing land use planning has been widely recognized (Sun, Zong, Ke, Wang, & Wang, 2011). Unfortunately, ESV is seldom used in practice, despite the clear advantages of this approach and a growing literature with many case studies that points to its usefulness. For example, as this study showed, both total ESV and ESV per capita decreased substantially with simultaneous growth in total GDP and GDP *per capita* over the past three decades in the HMA. Our finding is in agreement with other studies (Li et al., 2010; Liu, Li, et al., 2012), although ESV appears to decrease in response to land use at a highly variable rate. However, given robust economic growth and a rapid expansion of built-up land, it seems that the alarming level of ESV deterioration was not duly noted. Nor did it influence the government's land use policy.

The following several facts may explain why little attention has been paid to the ESV approach in the policy-making sphere. First,

Table 5
Change rates of ESV, GDP, built-up land, bare land, and total population in the study area from 1978 to 2008.

Factors	Overall change rate (%) (1978–2008)	Stage change rate (%)			
		Stage 1 (1978–1984)	Stage 2 (1984–1991)	Stage 3 (1991–2000)	Stage 4 (2000–2008)
Total ESV	−24.04	−16.92	1.01	−5.60	−4.11
Total GDP	3170.78	23.50	233.47	155.64	210.68
Built-up land	169.85	14.59	7.08	45.22	51.44
Bare land	310.32	−25.71	294.02	−12.91	60.96
Total population	72.40	8.49	10.19	28.89	11.89

due to the underlying uncertainties and constraints in present models of ESV (Harwood & Stokes, 2003), it is still difficult to persuade policy makers that ESV is a useful tool in practice. Because, in most of the case studies, ESV is calculated based on Costanza et al.'s simple method (1997), uncertain factors such as temporal and spatial scale effects, landscape heterogeneity, and numerous evaluation models will inevitably lead to confounding and doubtful results, although the coefficients of ESV associated with land cover types are usually adjusted in a given study area (Xie et al., 2003). For instance, a recent criticism is that in most existing studies, the ESV of built-up land is usually set as zero, regardless of any positive or negative effects of the built-up land on the environment (Bolund & Hunhammar, 1999; Li et al., 2010; Liu, Li, et al., 2012). However, in a fast-growing metropolitan area with millions of habitants, ignoring the effects of the built-up land may lead to biased estimates of regional ESV and may mislead decision-makers and planners. Moreover, trade-offs will occur when the provision of one ecosystem service is reduced as a consequence of the increased use of another ecosystem service (Rodríguez et al., 2006). According to our estimation, however, the ESV for all forms of land cover declined over the study period. We did not detect such trade-offs. In the face of rapid population growth and urban expansion, the roles of urban green space and traditional cultural resources (Rodríguez et al., 2006) is limited because these spaces occupy a very small proportion of the human-dominated ecosystem.

Secondly, knowledge gaps on how to accurately quantify ESV, how to apply it in practice, and how to communicate information to policy-makers and the general public are still thorny issues for scholars and urban/environmental planners. Thirdly, the government agencies responsible for land use planning tend to focus on land price and compensation for land requisition and relocation. Although the ESV approach of measuring regional ecosystem services in monetary value is an important and easy tool for managing land resources and development, there are very few skilled and qualified ESV auditors working in government agencies. Due to the complexity and uncertainty of assigning monetized value, the ESV has not been officially adopted and therefore serves only an ancillary role, without any support from laws or regulations. Consequently, local authorities tend to allow the conversion of low return lands into high return developmental land when facing tradeoffs between urban expansion and non-urban land use (Long, Tang, Li, & Heilig, 2007; Reynolds, 2000). In fact, an ESV approach integrated with land use and urban planning can yield both visual and computational outputs, which comprehensively reveal the relationship between gains and losses of vital ecosystem services, land use intensity, and socioeconomic change in the context of rapid urbanization. Unfortunately, so far, there are no straightforward solutions to address these issues. Thus, to a large degree, these technologies frustrate the stakeholders and decision-makers who are involved in the process of land use planning. Therefore, in future research, more accurate assessment methods and evaluation models for ESV are urgently needed to achieve sustainable land use and regional development.

Conclusions

In this study, land use dynamics, spatiotemporal patterns of ESV, and forces driving LULC change were analyzed in the fast-growing HMA from 1978 to 2008. The results show that over the past three decades, the areal extent of built-up land has increased by 169.85%. Approximately 80.37% of new built-up land was converted from other land cover types. Declining cropland and shrub account for 34.70% and 24.40% of new built-up land, respectively, followed by forest (9.90%), water (7.10%), and fallow land (4.20%). Simultaneously, bare land increased by 83.70%. Cropland, shrub, forest, and built-up land accounted for 29.40%, 31.20%, 15.20%, and 9.50% of the net increase in bare land, respectively. The HMA case study shows that robust socioeconomic growth and an ongoing increase in built-up land and bare land with low ESV inevitably lead to a decline in regional total ESV. According to our estimation, regional total GDP measured in constant year-2000 prices increased by a factor of 31.71, and total population increased by 72.40% from 1978 to 2008. LULC change and socioeconomic development are likely responsible for an overall decline of 24.04% in regional ESV. The ESV method is clearly useful in revealing these relationships. The velocity and complexity of the HMA's remarkable spatial restructuring process merits a careful examination and further assessment.

Given the ongoing trends of urbanization and socioeconomic development in the HMA, it is projected that an increasing demand for land use will place heavy pressure on natural and semi-natural ecosystems. Consequently, ecological functions that support the human-dominated ecosystem will be impaired. This paper points to the drastic spatial expansion of built-up land in many metropolitan areas, such as the HMA, under broad economic and spatial restructuring. Therefore, policies that aim to achieve long-term sustainable development must address the environmental effects of rapid urbanization and loss of semi-natural and natural lands. We suggest developing an integrated RS/GIS decision support system, not only for visually mapping of land use dynamics and spatiotemporal patterns of ESV based on retrospective analysis, but also for estimating and modeling population growth trends and evaluating the loss of natural and semi-natural lands and the ecological consequences that accompany the rapid expansion of urban areas. Further research along these lines should be encouraged, as we believe additional studies will be beneficial for the governmental authorities who engage in planning activities at various levels.

Acknowledgements

This study was supported by the Youth Science Foundation of Fudan University (Grant No. EXH591330) and the National Science Foundation of China (Grant Nos. 41171432 and 71173047). In addition, Hao Zhang would like to thank the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC), which generously provided LULC data for 1980, 1995, and 2000. The authors are grateful to Ms. L.J. Yan, N.N. Zhang, Y. Zhang, and Mr. P.F. Luo at the Hangzhou Municipal Bureau of Planning for their generous help in collecting the data. Additionally, many thanks to the graduate students L. Guo, L. Li, X.-X. Zheng, and Y.-F. Zhang for their hard work in conducting the field survey.

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