Influencing Factors on Forest Biomass Carbon Storage in Eastern China – A Case Study of Jiangsu Province

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Forest vegetation plays a crucial role in improving the ecological environment and maintaining the regional ecological balance. However, most studies pay little attention to the factors that can impact forest biomass carbon storage (FBCS). This research estimated the FBCS by combining relevant forest inventory data and models of continuous functions for biomass expansion factor. A modeling equation was then established and applied to examine the impact of socioeconomic factors on FBCS in Jiangsu, a coastal province in Eastern China, as a case study. The results showed that Jiangsu's FBCS increased by 20.28 Tg from 2005 to 2010, showing a prominent carbon sink effect but with spatial imbalance among the changes in carbon storage. Jiangsu's FBCS is significantly affected by land use factors (*e.g.,* forest area and cultivated area), population factors (*e.g.,* population density and urbanization), and economic development factors (*e.g.,* GDP). Relatively speaking, the forest area and GDP had positive effects on FBCS, while cultivated area, population density, and urbanization had significant negative effects.

Keywords: Forest biomass carbon storage; Forest inventory data; Social-economic impact; Jiangsu

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INTRODUCTION

The Earth's atmosphere, oceans, and terrestrial biosphere are three reservoirs of artificial sources of CO_2 (Fang and Guo 2007). As the largest part of the carbon stock in terrestrial ecosystems, the forest carbon pool stores nearly 2/3 of the terrestrial carbon (Ceulemans *et al*. 1999; Dixon *et al*. 1994), and plays an important role in stabilizing CO_2 concentration in the atmosphere. According to the estimation of the Intergovernmental Panel on Climate Change (IPCC 2007), carbon storage in the global terrestrial ecosystem is 2221 to 2477 Pg (1 Pg $=10^{15}$ g), of which about 20% is derived from vegetation and 80% originates from the soil. Forest vegetation, which covers 27.6% of the global land mass, accounts for about 77% of the whole vegetation carbon storage, and the forest ecosystem carbon storage per unit area is 1.9 to 5 times that of agricultural land. The Food and Agriculture Organization (FAO 2001) estimates that aboveground biomass per unit forest area is 109 Mg/ha and that global forest aboveground biomass reaches 422 Pg. Many scholars have explored the size, distribution, potential, estimation methods, *etc*., of forest vegetation carbon storage (Fang *et al*. 2001a; Liu *et al*. 2000; Luo *et al*. 2009; Wang *et al*. 2001; Wu *et al*. 2008; Zhou *et al*. 2008), which has laid a good foundation for studying forest biomass carbon storage (FBCS) in China.

Reducing carbon emissions and increasing carbon storage are the fundamental ways to respond to global climate change for all countries and areas. As it is known, there are many natural factors influencing FBCS, such as temperature, rainfall, conflagration, *etc.* (Bradford *et al*. 2013; Chen *et al*. 2013; Saunders *et al*. 2014; Wamelink *et al*. 2009; Zhang *et al*. 2010). The impact of socioeconomic factors, such as population, urbanization, GDP, and energy consumption, on carbon emissions has also received much attention (Kaya 1990; Ma *et al*. 2011; Schaffer 2008; Zhang *et al*. 2012; Zhang and Yang 2013). Regarding ways to increase carbon storage, some scholars calculate the carbon fixing capacity of forest vegetation at the national scale (Fang and Chen 2001b; Schimel *et al*. 2000), while other scholars estimate the carbon storage of relevant forest types at regional or provincial scales, such as the mangrove forest in Yingluo Bay, Guangdong Province (Wang *et al.* 2013), the ecological service forest in Zhejiang Province (Zhang *et al*. 2007), and the subalpine coniferous forest in Western Sichuan (Xian *et al.* 2009). Meanwhile some scholars analyze the impacts of a large-scale reforestation program and urbanization on carbon storage dynamics in Guangdong province (Zhou *et al*. 2008) and Xiamen City (Ren *et al*. 2011a), respectively, and assess the influence of tree species, forest age, and ownership changes on vegetation carbon storage in Fujian Province (Ren *et al*. 2011b). However, there have been few investigations that have comprehensively studied the impact of socioeconomic factors on FBCS for various regions of China. To enhance forest carbon sequestration, the Chinese government made a promise at the United Nations Climate Change Conference in September 2009 to increase forest coverage by 40 million ha and forest stock volume by 1.3 billion m^3 by 2020 from the 2005 levels. The realization of this goal depends on scientific decision-making and effective implementation by local governments with respect to forestry resources, policies, and technology.

There are four coastal provinces in Eastern China: Shandong, Jiangsu, Shanghai, and Zhejiang (see Fig. 1). These provinces accounted for 31.28% of China's GDP and 23.84% of the national forestry output value in 2010 (NBSC 2011; SFA 2011). However, the forest area and stock of these provinces are only 4.87% and 1.98%, respectively, of China's total (SFA 2010). Jiangsu Province has a total land area of 102.6 thousand km^2 and a total population of 78.66 million people, which are 1.06% and 5.87% of the country's totals, respectively (PGJ 2011).

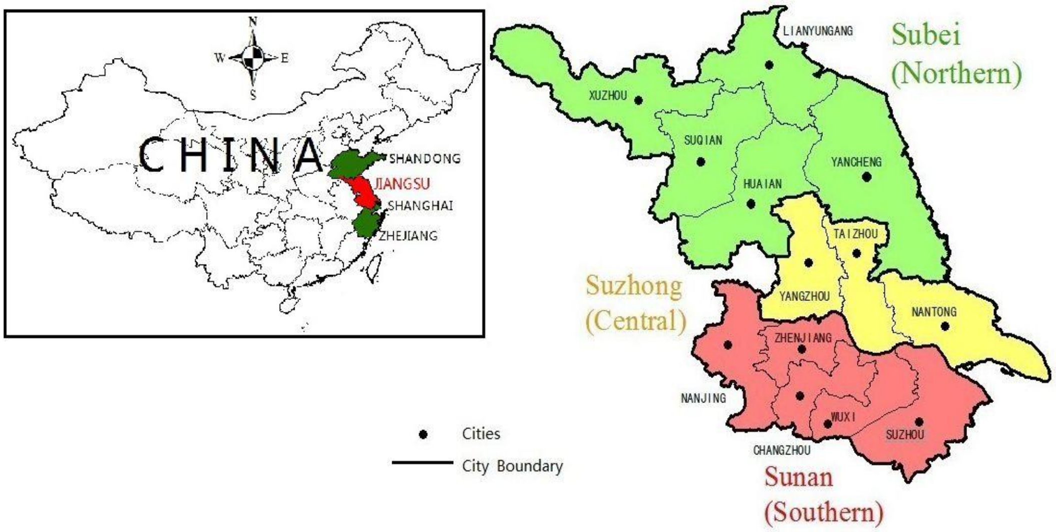

Fig. 1. Regions in Jiangsu Province, China

As one of the most developed provinces of China, Jiangsu's per capita GDP exceeded US $10,000 in 2012 and is ranked first at the provincial level nationwide (NBSC 2013). By contrast, Jiangsu's forest coverage (15.29%) is below the average level for China (20.36%) (SFA 2011), and its economic development is facing great ecological and environmental pressures. Geographically, a notion that has gained favor is a three-fold division of Jiangsu Province into the south (Sunan), the central (Suzhong), and the north (Subei) (Fig. 1). Using Jiangsu as a case study, this investigation aims to estimate the changes of the FBCS, to illustrate the potential impacts of socio-economic factors on FBCS, and to offer recommendations to enhance FBCS for Jiangsu and other coastal provinces in eastern China that have developed economies and poor forest resources.

METHODOLOGY

Estimation Method of FBCS

Average biomass, average expansion factor, and continuous functions for biomass expansion factor (BEF) are the three principal methods to calculate regional-scale forest biomass (Fang *et al*. 2002). Here, a function expressed as $BEF = a + b/x$ was used to obtain a variable BEF value for each forest type, where x (unit: m^3/ha) is the timber volume, and a (unit: Mg/m^3) and b (unit: Mg) are the corresponding constants for an arbor species (Fang and Guo 2007; Liu *et al*. 2000). The BEFs of major species of Jiangsu's arbor forest were calculated based on the Seventh and Eighth Forest Resource Inventory of the Jiangsu Province (JFB 2010, 2011a) (Table 1). The Eighth Forest Inventory of Jiangsu was organized by Jiangsu Forestry Bureau and implemented by Jiangsu Monitoring Center for Forest, which kept identical with the Seventh with respect to the sample plot range, quantities, shape, area and localization manner of sample trees. The investigation results comprehensively reflected the present situation, characteristics and change of forest resource, and the ecosystem in Jiangsu Province.

The arbor forest biomass (AFB) was calculated from the inventory data of the regional forest resource using the method of continuous functions for BEF,

$$AFB = \sum_{i=1}^{m} A_i X_i BEF_i \tag{1}$$

where, for the *i*th arbor forest species, A_i is the forest area (unit: ha), X_i is the corresponding timber volume per unit area (unit: m^3/ha), and BEF_i is the biomass expansion factor (unit: Mg/m^3).

Then, the FBCS for each region was estimated using the following equation,

$$FBCS = q(AFB + \sum_{j=1}^{n} A_j B_j) \tag{2}$$

where q is the carbon coefficient of the forest biomass and adapted as 0.5 (Fang *et al*. 2002); A_j (for j = 1, 2, 3) represents the area (unit: ha) of the economic forest, the bamboo forest (calculated by plant number), and the shrubbery, respectively; B_j (for j = 1, 2, 3) is the per unit biomass (unit: Mg/ha) of the economic forest, the bamboo forests, and the shrubbery, respectively.

Table 1. BEFs of Major Tree Species in Jiangsu Arbor Forests

Forest type		Constants		Stock per hectare X (m^3/ha)		BEF (Mg/m^3)	
		a (Mg/m^3)	b (Mg)	2005	2010	2005	2010
Broad-leaved forest	*Populus deltoides*	0.4969	26.973	47.89	62.18	1.060	0.931
	Mixed broadleaf	0.9788	5.3764	28.07	25.34	1.170	1.191
	Lignum cinnamomi camphorae	1.0357	8.0591	—	18.02	—	1.483
	Quercus	1.3288	-3.8999	—	76.5	—	1.278
	Other *Quercus*	1.1453	8.5473	52.48	53.03	1.308	1.306
	Ulmus pumila	0.9788	5.3764	35.12	—	1.132	—
	Paulownia	0.4158	41.3318	14.69	—	3.229	—
	Melia azedarach	0.9788	5.3764	14.05	—	1.361	—
	Sapium sebiferum	0.9788	5.3764	27.9	—	1.172	—
	Broussonetia papyrifera	1.1783	2.5585	—	30.81	—	1.261
	Ginkgo biloba	1.1783	2.5585	11.39	21.60	1.403	1.297
	Celtis sinensis	1.1783	2.5585	—	40.17	—	1.242
	Salix babylonica Linn.	0.9788	5.3764	30.36	19.70	1.156	1.252
	Robinia pseudoacacia	1.1783	2.5585	22.9	14.76	1.290	1.352
	Pterocarya stenoptera	0.9788	5.3764	36.14	25.83	1.128	1.187
	Hardwood	1.1783	2.5585	23.61	22.90	1.287	1.290
	Other soft broadleaf	0.7554	5.0928	29.78	9.01	0.926	1.679
Coniferous forest	*Metasequoia glyptostroboides*	0.4158	41.3318	82.96	108.96	0.914	0.795
	Cunninghamia lanceolata	0.4652	19.141	49.89	57.09	0.849	0.800
	Taxodium ascendens	0.4652	19.141	71.43	—	0.733	—
	Cupressus funebris Endl.	0.8893	7.3965	34.07	41.26	1.106	1.069
	Pinus elliottii	0.5292	25.087	—	52.49	—	1.007
	Pinus massoniana	0.5034	20.547	44.23	30.86	0.968	1.169
	Mixed conifer	0.8136	18.466	19.29	40.50	1.771	1.270
	Cedrus deodara	0.5292	25.087	—	15.33	—	2.166
	Pinus thunbergii Parl.	0.5292	25.087	23.72	22.61	1.587	1.639
	Pinus densiflora Sieb. et Zucc.	0.5723	16.489	7.79	4.50	2.689	4.237
	Pinus abroad	0.5723	16.489	47.55	—	0.919	—
	Other *Pinus*	0.5292	25.087	6.69	—	4.279	—
Mixed coniferous-broadleaf forest		0.8019	12.2799	26.26	39.78	1.270	1.111

Notes: "—"stand for 0 or no data.

When calculating the FBCS of prefectural-level cities, the average biomass of China's economic forest (23.7 Mg/ha) was taken as the economic forest biomass per unit area (B_1), and the average biomass of the shrubbery in the south of the Qingling Mountain Range and Huaihe River in China (19.76 Mg/ha) (Fang *et al*. 1996) was taken as the shrubbery per unit area (B_3). Per plant biomass of the bamboo forest varies from 0.02235 Mg to 0.02262 Mg, with the bamboo density (stand density) of 2788 to 4545 plant per hectare (Nie 1994).

The bamboo forest area accounts for 69.5%, and the average density is 4182 plants per hectare in Jiangsu Province, so bamboo biomass (B_2) was estimated in accordance with an average of 0.0225 Mg per plant. According to the similar wood density, the parameters of *Pterocarya stenoptera* were calculated with reference to mixed broadleaf trees, those of *Broussonetia papyrifera*, *Ginkgo biloba*, *Celtis sinensis*, and *Robinia pseudoacacia* were calculated in accordance with the hardwood class, and those of *Pinus elliottii*, *Cedrus deodara*, and *Pinus thunbergii parl*, which are generally found in coniferous forests, were all calculated in reference to other pines and coniferous forests.

Socioeconomic Model for Factors Influencing FBCS

FBCS is closely related to the quantity and quality of forest and is influenced by a variety of socioeconomic factors. However, there is usually limited knowledge of the specific forces driving these impacts. One key limitation to a precise understanding of these impacts is the absence of refined analytic tools. In past decades, some analytic tools, such as IPAT (Environmental impact (I) = Population (P)*Affluence (A)*Technology (T)) and STIRPAT (stochastic impacts by regression on population, affluence, and technology), were established to analyze the impacts of human behavior on carbon emissions (York *et al*. 2003). However, the model is deficient with respect to identifying the socioeconomic impacts on FBCS. Here, an equation is proposed to analyze the impacts of human behavior on FBCS,

$$FBCS = LA \times \frac{POP}{LA} \times \frac{FA}{POP} \times \frac{FBCS}{FA} \tag{3}$$

where *LA* is the land area; *POP* is the population; and *FA* is the forest area. Then, *POP*/*LA*, *FA*/*POP*, and *FBCS*/*FA*, respectively define population density (*PD*), per capita forest area (*PCFA*), and carbon density (*CD*).

To reduce the heteroscedasticity of the data and to eliminate the fluctuating trends of the variables, Equation (4) is obtained by taking the logarithm of Equation (3):

$$\ln FBCS = \ln LA + \ln PD + \ln PCF\mathrm{A} + \ln CD \tag{4}$$

Then, a general econometric model can be established:

$$\ln FBCS_{i,t} = f(L_{i,t}, P_{i,t}, D_{i,t}) + u_{i,t} \tag{5}$$

In Equation (5), *L* denotes land use structure factors such as cultivated land area and forest area; *P* represents population factors such as regional population density and structure (related economic and demographic data used in modeling are from Jiangsu Statistics Bureau) (JSB 2011); *D* means forest productivity factors such as forest unit volume, species structure, and age structure; *u* is the error term; the subscript *i* represents the region *i*; and *t* is the year of the statistical data.

In this paper, the impact of forest productivity factors on FBSC was not discussed due to the lack of forest resource inventory data from individual counties in Jiangsu.

RESULTS AND DISCUSSION

Sustained Growth of FBCS

Over the past two decades, forest stock has had sustainable growth in Jiangsu Province, and the forest annual growth has been higher than the forest consumption rate. This was especially true during 2005 to 2010, during which time the FBCS increased from 25.89 Tg to 46.17 Tg, with an annual growth rate of 12.27% (Table 2); this rate was higher than the 9.3% annual growth rate from 2000 to 2005 (Wang *et al*. 2010). Thus, during the past five years, the FBCS of Jiangsu increased rapidly and Jiangsu forests were a significant "carbon sink".

Table 2. Carbon Storage Change and Distribution in Jiangsu Forests

Region	City	Carbon Storage (Tg)			
		2005	2010	Increment (2005-2010)	Annual growth rate (%)
Sunan	Nanjing	2.37	3.88	1.51	10.36
	Suzhou	0.97	2.04	1.07	16.03
	Wuxi	1.19	2.33	1.14	14.38
	Changzhou	1.06	1.99	0.93	13.43
	Zhenjiang	0.83	2.81	1.98	27.62
Suzhong	Nantong	0.76	2.55	1.79	27.39
	Yangzhou	1.35	2.01	0.66	8.29
	Taizhou	1.06	1.86	0.80	11.90
Subei	Xuzhou	4.93	8.06	3.13	10.33
	Huaian	3.49	6.14	2.65	11.96
	Yancheng	2.13	4.27	2.14	14.92
	Lianyungang	2.05	3.39	1.34	10.58
	Suqian	3.70	4.84	1.14	5.52
Total		25.89	46.17	20.28	12.27

Note: $\text{Average annual growth rate} = \left(\sqrt[5]{\frac{CarbonStorage_{2010}}{CarbonStorage_{2005}}}\right) - 100\%$

The FBCS mainly came from the arbor forest, which accounted for 81.18% and 76.86% of the total for 2005 and 2010, respectively. However, the average carbon density of major tree species of arbor forests in Jiangsu was 23.40 Mg/ha and 25.78 Mg/ha in 2005 and 2010 (Table 3), respectively, which is close to Fang's (2001a) calculation of 25.3 Mg/ha, but less than the national average of 38.05 Mg/ha (Fang and Chen 2001b) in 1998 and 42.82 Mg/ha (Li and Lei 2010) in 2004. In the coastal provinces of Eastern China, carbon density of arbor forests of Jiangsu were similar to Shandong and Zhejiang, and exceeded Shanghai (Li and Lei 2010), which was similar to the situation of timber volumes per unit area among these provinces. For example, the timber volume of Jiangsu, Shandong, and Zhejiang was 47.04 m^3/ha, 40.60 m^3/ha, and 43.76 m^3/ha, respectively, while Shanghai was just 29.69 m^3/ha (SFA 2010). For Jiangsu's arbor forests, young forest and middle aged forest constituted a high proportion, which is the main reason why Jiangsu appeared to have lower biomass. The Eighth Forest Resource Inventory of Jiangsu Province (2011) shows that the area and volume of the young forest accounted for 35.26% and 13.55% of the total arbor forests, respectively, while the middle aged forest accounted for 47.37% and 57.30%, respectively.

Table 3. Carbon Storage of Major Tree Species of Jiangsu Arbor Forests

Forest type		Area A_i (10^3 ha)		Carbon storage (10^3 Mg)		Carbon density (Mg/ha)	
		2005	2010	2005	2010	2005	2010
Broad-leaved forest	*Populus deltoides*	623.6	826.3	15828.8	23909.1	25.38	28.94
	Mixed broadleaf	15.2	138.1	249.7	2083.9	16.43	15.09
	Lignum cinnamomi camphorae	—	39.6	—	529.1	—	13.36
	Quercus	—	7.2	—	351.9	—	48.88
	Other *Quercus*	13.2	3.6	453.1	124.7	34.33	34.64
	Ulmus pumila	1.2	—	23.9	—	19.88	—
	Paulownia	0.8	—	19.0	—	23.72	—
	Melia azedarach	0.8	—	7.6	—	9.56	—
	Sapium sebiferum	0.8	—	131.0	—	16.34	—
	Broussonetia papyrifera	—	8.4	—	163.2	—	19.43
	Ginkgo biloba	31.6	8.6	252.4	120.4	7.99	14.00
	Celtis sinensis	—	3.6	—	89.8	—	24.95
	Salix babylonica Linn.	4.0	6.1	70.2	75.2	17.55	12.33
	Robinia pseudoacacia	9.6	7.2	141.8	71.8	14.77	9.98
	Pterocarya stenoptera	2.0	3.6	40.7	55.2	20.37	15.33
	Hardwood	48.4	13.2	735.3	195.0	15.20	14.77
	Other soft broadleaf	24.0	7.2	331.0	42.8	13.79	5.95
Coniferous forest	*Metasequoia glyptostroboides*	22.4	18.0	849.3	779.7	37.92	43.32
	Cunninghamia lanceolata	19.2	19.2	406.5	438.7	21.17	22.85
	Taxodium ascendens	1.6	—	41.9	—	26.18	—
	Cupressus funebris Endl.	18.0	14.4	339.2	317.4	18.85	22.04
	Pinus elliottii	—	10.9	—	288.1	—	26.43
	Pinus massoniana	22.8	14.5	488.0	261.6	21.40	18.04
	Mixed conifer	1.6	4.8	27.3	123.4	17.08	25.71
	Cedrus deodara	—	9.6	—	159.4	—	16.60
	Pinus thunbergii Parl.	0.80	3.6	150.5	66.7	18.82	18.53
	Pinus densiflora Sieb. et Zucc.	1.2	1.2	12.6	11.4	10.48	9.53
	Pinus abroad	14.0	—	305.9	—	21.85	—
	Other *Pinus*	0.8	—	11.4	—	14.31	—
Mixed coniferous-broadleaf forest		13.6	34.8	226.8	768.7	16.67	22.09
total		898.4	1203.7	21026.1	31027.4	23.40	25.78

Moreover, as the leading plantation tree in Jiangsu, the carbon density of *Populus* was increased from 25.38 Mg/ha in 2005 to 28.94 Mg/ha in 2010, close to the calculation of 25 to 28 Mg/ha (Liu *et al*. 2000) and the average carbon storage (30 Mg/ha) of plantation forest ecosystems (Fang and Chen 2001b). An estimation of the carbon storage of *Populus* in Jiangsu was up to 74.1 ± 8.3 Mg/ha, based on taking 10-year-old *Populus*

(*Populous deltoides* Bartr. cv. "Lux") plantation as the example (Tang *et al*. 2004). In fact, among Jiangsu's *Populus* plantations, the area of the young forest and the middle-aged forest accounted for 21.4% and 72.36% (JFB 2010), respectively, which indicated that the FBCS of Jiangsu has the potential for a tremendous increase.

As can be seen from the regional distribution of all forests (Fig. 2), Subei contributed 57.83% to the FBCS, which was the largest in the province, followed by Sunan and Suzhong, which accounted for 28.26% and 13.91%, respectively. For the regional distribution of the arbor forests for the FBCS, Subei accounted for 67.38%, whereas Sunan and Suzhong contributed 20.66% and 11.97%, respectively; with respect to the regional distribution of the bamboo forest for the FBCS, Sunan contributed 66.96%, while Subei and Suzhong contributed 18.24% and 14.79%, respectively. The economic forest's FBCS for the regions was relatively evenly distributed. The FBCS distribution for the regions due to shrubbery was 38.98% in Subei and approximately 40.37% in Sunan, with the balance in Suzhong.

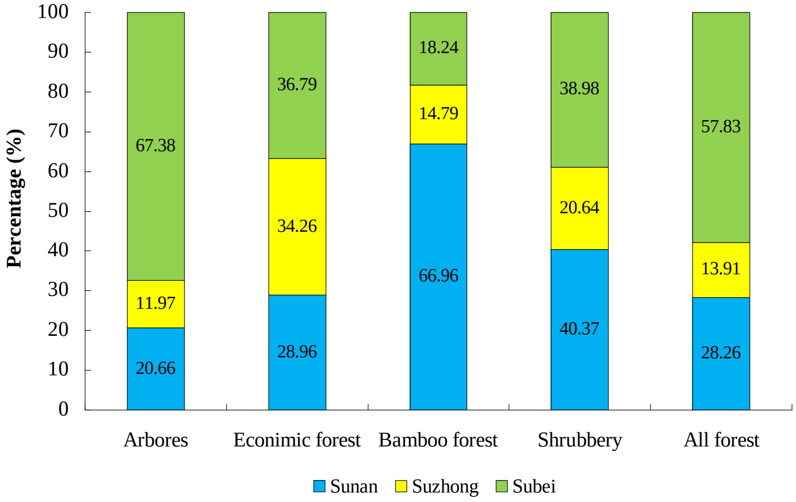

Fig. 2. FBCS contributions of different region for different forest classifications in Jiangsu (2010)

Factors Influencing FBCS

This paper sets FBCS as a dependent variable and takes land area, cultivated land area, forest area, population, population density, urbanization rate, GDP, highway mileage, number of forestry workers, and other factors as independent variables to further identify the factors influencing FBCS. Based on the relevant statistical data from 51 sample counties of Jiangsu in 2010 (JFB 2011a; JSB 2011), a multiple regression analysis was carried out by Stata 10.0 after determining the logarithmic transformation of each variable index. [It should be noted that all data from municipal districts are excluded in the analysis considering the cities' forest resources are relatively fixed and the growth of forest land is limited.] The individual independent variables passing the statistical correlation test (at the 90% level or greater) are shown in Table 4. It was found that forest area and GDP were the main factors boosting the growth of FBCS, whereas cultivated land area, population density, and the urbanization rate had significant negative effects on FBCS.

In point of the influence of GDP, with the increasing pressure of environment and ecological consciousness, GDP growth of a region could imply more forestry inputs. In fact, the forestry industry, no matter whether one considers the forestry products industry or forest tourism, is a resources-oriented industry, while forest sustainable management can promote the coordinated growth of economy and ecology. For example, both forest resources and output value of forestry industry in Jiangsu have been increasing during the past decade. Therefore, economic development factors can be understood as forestry investment ability, which is beneficial to the growth of FBCS. The other influence factors are discussed in the next section.

Table 4. Estimation Results of Factors Influencing Jiangsu's FBCS

Variables	*Ln* (FBCS)
Ln (forest area)	0.922*** (0.0331)
Ln (cultivated land area)	-0.131** (0.0555)
Ln (population density)	-0.117* (0.0612)
Ln (urban rate)	-0.177* (0.0887)
Ln (GDP)	0.0872** (0.0367)
Constant	5.544*** (0.655)
Observations	51
R-squared	0.975
Standard errors in parentheses: *** p<0.01, ** p<0.05, * p<0.1	

Notes: Data in bracket is standard error.

Land use structure

The change in land use caused by human activities has a significant influence on terrestrial ecosystem carbon storage (Jiao *et al*. 2010). For example, changes from woodland to other land use types, especially urbanized land, will result in less plant material to sequester carbon dioxide (Houghton 2002), while changes from other land use types to woodlands can increase the vegetation biomass and carbon storage. In Table 4, forest area and cultivated land area reflect the influence of land use structure on FBCS. More specifically, forest area has a positive correlation with FBCS at the 99% significance level. Thus, a forest area increased by 1% can increase the FBCS by 0.922%, when the other independent variables are fixed. Cultivated land area has a negative correlation with FBCS at a 95% significance level. Thus, under the same conditions, every 1% increment in cultivated land will lead to a decrease of 0.131% in the FBCS.

Over the past three decades, China's economy has grown the fastest among all major nations. In contrast, China's environment is increasingly deteriorating (Liu *et al*. 2008). To mitigate negative environmental impacts, China initiated several National Key Forestry Programs in the late twentieth century, such as the Natural Forest Conservation Program (NFCP), the Grain for Green Program (GGP), the Shelterbelt Construction Program (SCP), and the Fast-Growing and High-Yielding Plantation Program (FHPP). As one of the provinces implementing FHPP, which aims to increase the effective supply of timber and timber products to meet the needs of socioeconomic development and to implement other conservation programs, Jiangsu's forest land area has maintained steady growth. Since 2003, in accordance with the requirements for provincial ecological reconstruction, the Jiangsu government made a policy decision on the "Green Jiangsu Program" (GJP). As the largest ecological engineering endeavor in Jiangsu, the project further increased the pace of afforestation across the province. From 2003 to 2009, the area of the province's total afforestation was up to 810.7×10^3 ha, which was higher than the 30 years before the implementation of the GJP; the forest coverage rate increased by 1.1% annually. Both the forest area and volume increased, and the amount of growth of forests were higher than the consumption rate, which resulted in a growing net production rate. Therefore, these policies can be seen as a primary factor for the significant increase in the FBCS of Jiangsu Province.

Cultivated land is one of the important land use types for human survival. International experience shows that rapid economic growth is always accompanied by a shift in land use from agriculture to industry, infrastructure, and residential use (Ramankutty *et al*. 2002). Accompanying China's post-1978 economic reforms, Jiangsu's cultivated land resources continued to be reduced over the past 3 decades, which undoubtedly contributed to the increase of FBCS in the Jiangsu Province. However, in the context that China will keep cultivated land use safe from breaking through the "red line", the increase in forest area certainly will be restricted. According to the 12th Five-Year Plan (2010-2015) with respect to Jiangsu forestry development, new afforestation areas will be increased by 20 thousand ha (JFB 2011b); this will result in an increase in the FBCS of 5.16 Tg in accordance with the average forest carbon density (25.78 Mg/ha) of Jiangsu's arbor forests. However, if the average carbon density of Jiangsu's arbor forests can be increased from 25.78 Mg/ha to 38.05 to 42.82 Mg/ha (*i.e.*, the national average level) (Fang and Chen 2001b; Li and Lei 2010) by improving the productivity of forest land, the FBCS will increase from 16.88 to 23.45 Tg without any increase in the forest area. Therefore, to increase terrestrial ecosystem carbon storage in Jiangsu and other coastal provinces, some measures, such as optimizing land use structure, strengthening woodland protection, and improving the comprehensive productivity of forest land, should be considered in order to enhance the forest stock and its carbon sequestration capacity.

Population and urbanization

Human activity has strongly changed land cover and land quality throughout China, and forests have been subjected to a long period of human disturbances (Wang *et al*. 2001). For example, with the development of urbanization, more and more farmland, woodland, and grassland has been converted to urbanized land, which results in the land area being converted from a carbon sink to a carbon source (Deng *et al*. 2009). Table 4 shows that population density and urbanization rate had a negative effect on the FBCS at the 90% significance level. Thus, an increase of 1% of the population density and the urbanization rate will result in the FBCS being reduced by 0.117% and 0.177%, respectively.

Population density has become a dominant factor affecting vegetative carbon density on a provincial scale. In the eastern part of China, because of high population density (*e.g.*, Shanghai, Jiangsu, and Zhejiang Provinces, where the population densities are more than 400 individuals/km^2), the carbon density of forest ecosystems is less than 9 Mg/ha. In contrast, in western China, where the population density is less than 102 individuals/km^2, the carbon density was more than 46 Mg/ha (Wang *et al*. 2001). Among China's mainland provinces, Jiangsu's population density was ranked the highest in 2011, with 770 individuals/km^2, much higher than the national level of 140 individuals/km^2 during the same period. However, the changes in population density in Jiangsu were relatively small during the past 10 years. Relatively speaking, the population density of Sunan, at 1150 individuals/km^2 in 2011, was higher than the average level of the province. Because the population of Sunan has remained in a high-density state, and considering China's unchanged one-child policy and the synchronous urbanization in each region, the effects of population density on forest resources and carbon storage were relatively limited. In Suzhong and Subei, changes in population density appeared to be stable, with a slight decline. If this trend continues, the changes in population density in these regions will not have a significant negative impact on the FBCS, and may even increase the FBCS due to the population decrease.

China has experienced rapid urban transformation, represented by significant changes in its demographic composition and large-scale expansion of the urban landscape. In 2011, China's urbanization rate reached 51.3% and the urban population was up to 690 million people (exceeding the rural population for the first time). Over the next 20 years, China's urbanization will remain in the stage of rapid development and is expected to grow at an average annual rate of 1% (Jian and Huang 2010). Jiangsu’s urbanization rate reached 61.9% in 2011 (JSB 2012), higher than the national average, but it appeared to vary in different regions. For example, the urbanization rate in Sunan was more than 70%, whereas the corresponding rates in Suzhong and Subei were only 57.7% and 53.3%, respectively, in 2011. Along with massive urban infrastructure construction, such as roads and buildings, urbanization will inevitably enhance the demand for land occupancy, in particular non-industrial land. As far as Sunan is concerned, the negative effects of urbanization on the FBCS will not be obvious because potential urbanization space is relatively small. In comparison, with the rapid urbanization development in Suzhong and Subei, the forest area and volume will be subjected to certain restrictions due to the negative effects of urbanization, as mentioned above.

Studies have shown that urbanization has a significant impact on the emission of carbon dioxide (Jyoti and Vibhooti 1995; York *et al*. 2003). Those in China indicate that urbanization will increase carbon emissions (Lin and Liu 2010; Zhu and Peng 2012). In response to such change, many plans have been made to reduce carbon emissions, such as by the use of biofuels, carbon capture, and planning for energy use in industrial areas. Reductions in carbon emissions, however, will be difficult to achieve, because most of these plans face considerable difficulties created by technological problems as well as the business and politics of energy use. As a result, enhancing the function of forest-based carbon sinks by adjusting land use patterns seems to be an effective way to increase carbon storage for terrestrial ecosystems.

CONCLUSIONS

1. With an average annual growth of 4.06 Tg, the FBCS of Jiangsu Province increased from 25.89 Tg in 2005 to 46.17 Tg in 2010; this increase was attributed to the contribution from the arbor forests. However, the average carbon density of major tree species of Jiangsu’s arbor forests is only 25.78 Mg/ha, which is less than the national average. The cause for this observation is the fact that Jiangsu’s forest resources are characterized by low forest cover, undesirable age-class distribution, and relatively low volume of growing stock.
2. The spatial distribution of the FBCS in Jiangsu was uneven; Subei, Sunan, and Suzhong contributed 57.83%, 28.26%, and 13.91% of the total FBCS in 2010,

respectively. In theory, according to the ecological compensation principle of "those who get benefit will make compensation", Subei should receive carbon credits from Sunan due to its higher forest eco-contribution.

3. FBCS is significantly affected by land use factors (*e.g.,* forest area and cultivated area), population factors (*e.g.,* population density and urbanization), and economic development factors (*e.g.,* GDP). Relatively speaking, forest area and GDP have positive effects on the FBCS, while cultivated area, population density, and urbanization have significant negative effects.
4. Among land use factors, large-scale afforestation under the ecological programs (*e.g.,* SCP, FHPP, and GJP) resulted in extensive new forest area and hence enhanced the carbon sequestration capacity of terrestrial ecosystems in Jiangsu and other coastal provinces in Eastern China. In the economically developed regions, such as Sunan, the population density and urbanization rate are significantly higher than the national average, but this is not expected to bring about significant negative effects on regional FBCS. In Subei, however, where population density and urbanization are relatively low, the increase in FBCS will be inhibited to some extent by rapid urbanization.

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