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# Effects of Afforestation on Carbon Storage in Boyang Lake Basin, China

WU Dan[1], SHAO Quanqin[1], LI Jia[2]

(1. *Institute of Geographic Sciences and Natural Resources Research*, *Chinese Academy of Sciences*, *Beijing* 100101, *China*; 2. *Xinjiang Institute of Ecology and Geography*, *Chinese Academy of Sciences*, *Ürümqi* 830011, *China*)

**Abstract:** By using field survey data from the sixth forest inventory of Jiangxi Province in 2003, the biomass and carbon storage for three studied species (*Pinus massoniana*, *Cunninghamia lanceolata*, and *Pinus elliottii*) were estimated in Taihe and Xingguo counties of Boyang Lake Basin, Jiangxi Province, China. The relationship between carbon density and forest age was analyzed by logistic equations. Spatio-temporal dynamics of forest biomass and carbon storage in 1985–2003 were also described. The results show that total stand area of the three forest species was $3.10 \times 10^5$ ha, total biomass 22.20 Tg, vegetation carbon storage 13.07 Tg C, and average carbon density 42.36 Mg C/ha in the study area in 2003. Carbon storage by forest type in descending order was: *P. massoniana*, *C. lanceolata* and *P. elliottii*. Carbon storage by forest age group in descending order was: middle stand, young stand, near-mature stand and mature stand. Carbon storage by plantation forests was 1.89 times higher than that by natural forests. Carbon density of the three species increased 8.58 Mg C/ha during the study period. The carbon density of Taihe County was higher in the east and west, and lower in the middle. The carbon density of Xingguo County was higher in the northeast and lower in the middle. In general, the carbon density increased with altitude and gradient. Afforestation projects contribute significantly to increasing stand area and carbon storage. Appropriate forest management may improve the carbon sequestration capacity of forest ecosystems.

**Keywords:** carbon storage; carbon density; forest inventory data; Biomass Expansion Factor; Boyang Lake Basin

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## 1 Introduction

Forests have higher productivity than other terrestrial ecosystems. Forest carbon storage accounts for about two-thirds of the global terrestrial ecosystems. Forests play an invaluable role in regulating carbon and oxygen balance, slowing the rise of $CO_2$ concentration, and responding to global climate change (Dixon *et al.*, 1994; Liu *et al.*, 2000; Houghton, 2007). Therefore, estimating carbon storage in forest ecosystems and evaluating their carbon sink capacities have been the focus of numerous studies.

Forest biomass and carbon storage are basic parameters that reflect the functions of forest ecosystems. Methods used to estimate these parameters can be summarized mainly as sample plot survey (Piao *et al.*, 2009; Liu and Li, 2011), model simulation (Seely *et al.*, 2002; Li *et al.*, 2004; Tian *et al.*, 2011) and remote sensing inversion (Dong *et al.*, 2003; Turner *et al.*, 2004). Brown and Lugo (1984) first proposed the volume-derived method. Fang *et al.* (1996; 2001) gave the linear relation of 21 forest types in China and calculated total biomass and net production. However, they did not distinguish the contribution of natural forests and artificial plantation. Xu *et al.* (2007) analyzed a fitting relation of forest biomass and carbon storage in China using

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Corresponding author: SHAO Quanqin. E-mail: shaoqq@lreis.ac.cn

national inventory data of six periods from 1973 to 2003, and calculated dynamic changes during that period. However, they did not provide spatial distribution maps of carbon storage.

The Boyang Lake Basin is the main forested region of South China. Long-term reclaiming farmland from forests and lakes had caused serious damage to the ecological environment and natural resources. Since the 1980s, the Mountain-River-Lake (MRL) program has been implemented to help reverse the severe environmental degradation and land deterioration. The MRL program has achieved remarkable success in promoting vegetation recovery (Deng, 1990; Zhang *et al.*, 2007; Zheng *et al.*, 2008). Taihe and Xingguo counties in the Boyang Lake Basin are two typical examples. In 1981, forest cover of Taihe County was only 31.3% (Kang *et al.*, 1993). Through intensive plantation cultivation, forest cover of the county reached 61% in 2003 (Huang, 2009). Soil and water loss in Xingguo County was very serious because of its history of steel production. Furthermore, burning and other damage from humans caused great loss of forest areas. By 1982, forest cover of Xinguo County was only 33.8%. After 20 years of comprehensive management, forest cover exceeded 70% (Cheng *et al.*, 2004; Xie and Chen, 2009). Afforestation projects contribute significantly to increased carbon sequestration and improved carbon sink capacity (Richter *et al.*, 1999; Farley, 2007). Consequently, it is important to estimate the biomass and carbon storage capacity of the forest plantation ecosystem.

Based on the field survey data from the sixth forest inventory of Jiangxi Province in 2003, this paper investigated the curve relations between carbon density and ages of *Pinus massoniana*, *Pinus elliottii* and *Cunninghamia lanceolata*, and estimated the changing trend of carbon density of the three species in the Boyang Lake Basin from 1985 to 2003. Also, this paper gave the spatial distribution of carbon storage of the three species and distinguished the contribution of natural forests and artificial plantation to carbon storage, which could provide certain basis for forest management and planning.

## 2 Materials and Methods

### 2.1 Study area

The study area (26°03′–26°59′N, 114°57′–115°51′E) includes Taihe and Xingguo counties in the Boyang Lake Basin of Jiangxi Province, China (Fig. 1). The main landforms are mountains and hills. The area is within the subtropical monsoon climate zone, which has a mild climate and abundant precipitation. Annual temperature is about 18℃ and annual precipitation about 1500 mm. Forest vegetation types include *P. massoniana*, *P. elliottii*, *C. lanceolata*, *Liquidambar formosana*, *Phyllostachys pubescens*, *Camellia oleifera* and so on.

### 2.2 Data sources

Forest subcompartment data were based on the forest inventory of Jiangxi Province done in 2003. We collected 148 subcompartment maps of Taihe County, 204 maps of Xingguo County, and corresponding forest inventory data. Attributes of the data included plot coor-

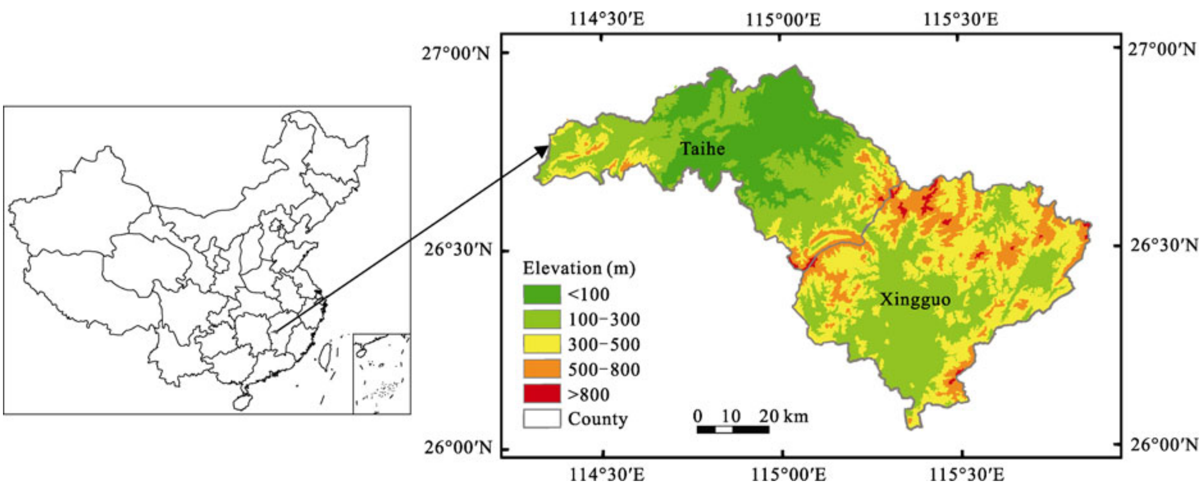


**Fig. 1** Location and elevation of study area

dinates, elevation, gradient, area, dominant species, mean age, average tree height and timber volumes. As *P. massoniana*, *P. elliottii* and *C. lanceolata* were the main species planted in the region, they were selected as the studied species of this paper. The inventory data also had origin information, so both artificial and natural parts of the three species were considered.

## 2.3 Methods

### *2.3.1 Biomass Expansion Factor*

(1) Biomass of forest vegetation

We used the Biomass Expansion Factor method to estimate forest biomass of the studied species of *P. massoniana*, *P. elliottii*, and *C. lanceolata*. Conversion parameters are shown in Table 1 (Fang *et al.*, 1996; 2001; 2002). The relationship between aboveground biomass and per unit timber volume is estimated as follows (Fang *et al.*, 1996):

$$B = a \times V + b \quad (1)$$

where $B$ is aboveground biomass per unit area (t/ha); $V$ is timber volume per unit area ($m^3$/ha); and $a$ and $b$ are parameters.

**Table 1** Parameters for transfer equation of forest biomass and timber volume in study area

| Vegetation type | *a* | *b* | Above-ground biomass/ Below-ground biomass |
|---|---|---|---|
| *P. massoniana* | 0.5101 | 1.0451 | 6.23 |
| *P. elliottii* | 0.5168 | 33.2378 | 4.12 |
| *C. lanceolata* | 0.3999 | 22.5410 | 4.70 |

(2) Carbon storage of forest vegetation

Carbon storage of forest vegetation consists of the storages in the tree layer, floor vegetation and ground litter. The carbon storage of tree layer was calculated by the product of subcompartment biomass and stand carbon content. The carbon content was obtained from the data collected from Qianyanzhou Experimental Station of the Chinese Academy of Sciences in Taihe County, giving *P. massoniana* at 55.23%, *P. elliottii* 54.31% and *C. lanceolata* 53.75% (Shen *et al.*, 2006). Carbon storages of floor vegetation and ground litter were determined from subcompartment area and carbon density. And the carbon density data were collected from Wang *et al.* (2007) (Table 2).

**Table 2** Carbon density of floor vegetation and ground litter in study area (Mg C/ha)

| Vegetation type | Floor vegetation | Ground litter |
|---|---|---|
| *P. massoniana* | 5.0 | 0.25 |
| *P. elliottii* | 3.9 | 0.70 |
| *C. lanceolata* | 3.3 | 0.44 |

Source: Wang *et al.*, 2007

### *2.3.2 Biomass organ distribution*

(1) Calculation of trunk biomass

Trunk biomass was calculated with trunk volume and density of dry matter. The density was determined from the data collected at Qianyanzhou Station, giving *P. massoniana* at 346.6 kg/$m^3$, *P. elliottii* 298.9 kg/$m^3$ and *C. lanceolata* 298.8 kg/$m^3$ (Li *et al.*, 2006).

(2) Calculation of entire plant biomass and carbon storage

Biomass of the entire tree was estimated via the distribution proportion of organs among different stands and ages. Researchers have summarized the biomass ratio of each organ for the three species at different ages (Table 3) (Yang, 2007; Shao *et al.*, 2009). Carbon stor-

**Table 3** Biomass ratio of each organ at different ages in study area (%)

| Vegetation type (age) | Above-ground | | | Root | Total |
|---|---|---|---|---|---|
| | Stem | Branch | Foliage | | |
| Mature stand forest of *P. massoniana* (22) | 63.19 | 15.75 | 2.97 | 18.09 | 100 |
| Middle stand forest of *P. massoniana* (15) | 74.95 | 15.74 | 3.94 | 5.37 | 100 |
| Young stand forest of *P. massoniana* (9) | 76.86 | 13.00 | 5.58 | 4.56 | 100 |
| Mature stand forest of *P. elliottii* (22) | 42.53 | 39.36 | 6.54 | 11.57 | 100 |
| Middle stand forest of *P. elliottii* (12) | 44.10 | 26.64 | 13.98 | 15.28 | 100 |
| Young stand forest of *P. elliottii* (8) | 32.34 | 26.77 | 21.46 | 19.43 | 100 |
| Mature stand forest of *C. lanceolata* (22) | 71.89 | 12.82 | 7.69 | 7.60 | 100 |
| Middle stand forest of *C. lanceolata* (14) | 67.01 | 11.01 | 9.22 | 12.76 | 100 |
| Young stand forest of *C. lanceolata* (9) | 59.85 | 9.13 | 9.74 | 21.28 | 100 |

age of the entire tree was calculated by the product of biomass and carbon content.

#### *2.3.3 Parameter fitting*

Based on field survey data of the three species measured at Qianyanzhou Station in 2007, we fitted a linear relationship between forest biomass and timber volume using the Equation (1) (Table 4).

**Table 4** Fitting parameters of forest biomass and timber volume in study area

| Vegetation type | *a* | *b* | $R^2$ |
|---|---|---|---|
| *P. massoniana* | 0.719 | 35.78 | 0.995 |
| *P. elliottii* | 0.573 | 63.40 | 0.992 |
| *C. lanceolata* | 0.387 | 73.38 | 0.969 |

### 2.4 Verification

We chose Qianyanzhou Station to verify results of the above three methods. First, the pattern of small watershed comprehensive management of Qianyanzhou was typical (Ni and Deng, 1990; Zhang, 2002). Most plantation patterns of forests in the Poyang Lake Basin and even the entire red soil hilly region were based on the Qianyanzhou pattern. Second, there have been numerous related studies conducted in Qianyanzhou (Shen *et al.*, 2006; Li *et al.*, 2006; Yang, 2007; Shao *et al.*, 2009).

We used ArcGIS software to establish a database that combined subcompartment maps and forest inventory data. We estimated the carbon densities of the three species using the methods described above, and compared results with related studies. Carbon densities determined by the Biomass Expansion Factor (Method I) and biomass organ distribution (Method II) were lower than those by parameter fitting (Method III). Densities determined by parameter fitting were close to those of the previous studies (Table 5).

## 3 Results and Analyses

### 3.1 Carbon storage and carbon density of three studied species in 2003

Parameter fitting method was chosen to estimate the carbon storage of three studied species in the study area. In 2003, total stand area of the three studied species (including artificial and natural forests) was 3.10 × $10^5$ ha, total biomass 22.20 Tg, vegetation carbon storage 13.07 Tg C, and average carbon density 42.36 Mg C/ha. Carbon storage by these different forest species in descending order was *P. massoniana*, *C. lanceolata* and *P. elliottii* (Table 6). *P. massoniana* sequestered the most carbon, since it occupied the largest area of the forest. Carbon storage by forest age groups in descending order was middle stand, young stand, near-mature stand and mature stand. Carbon density of forest vegetation increased with stand age (Table 7). The amount of carbon stored by plantation forests was 1.89 times greater than that by natural forests (Table 8). *P. massoniana* and *C.*

**Table 5** Comparison of carbon densities obtained by different methods and studies at Qianyanzhou Station (Mg C/ha)

| Vegetation type | Method I | Method II | Method III | Shen *et al.*, 2006 | Li *et al.*, 2006 | Shao *et al.*, 2009 |
|---|---|---|---|---|---|---|
| *P. massoniana* | 17.09 | 15.22 | 39.71 | 47.04 | 47.94 | 66.06 |
| *P. elliottii* | 48.57 | 27.58 | 57.75 | 59.73 | 45.14 | 71.42 |
| *C. lanceolata* | 39.27 | 22.59 | 59.05 | 64.79 | 37.52 | 81.96 |

Notes: Method I, Biomass Expansion Factor; Method II, biomass organ distribution; Method III, parameter fitting

**Table 6** Biomass, carbon storage and carbon density for three studied forests in study area

| Vegetation type | Area ($10^3$ ha) | Biomass (Tg) | Carbon storage (Tg C) | Carbon density (Mg C/ha) |
|---|---|---|---|---|
| *P. massoniana* | 170.97 | 10.03 | 6.32 | 37.43 |
| *P. elliottii* | 36.09 | 3.01 | 1.74 | 48.04 |
| *C. lanceolata* | 103.32 | 9.16 | 5.01 | 49.01 |

**Table 7** Biomass, carbon storage and carbon density of different age groups in study area

| Age group | Area ($10^3$ ha) | Biomass (Tg) | Carbon storage (Tg C) | Carbon density (Mg C/ha) |
|---|---|---|---|---|
| Young stand | 120.47 | 7.24 | 4.48 | 37.15 |
| Middle stand | 157.10 | 12.02 | 6.96 | 44.83 |
| Near-mature stand | 27.13 | 2.40 | 1.34 | 50.03 |
| Mature stand | 5.68 | 0.54 | 0.29 | 53.51 |

**Table 8** Biomass, carbon storage and carbon density of different stand origins in study area

| Stand origin | Area ($10^3$ ha) | Biomass (Tg) | Carbon storage (Tg C) | Carbon density (Mg C/ha) |
|---|---|---|---|---|
| Artificial forests | 205.56 | 14.49 | 8.54 | 42.00 |
| Natural forests | 104.81 | 7.71 | 4.53 | 43.02 |

*lanceolata* were the main natural forest carbon sinks, with ratios of 73.31% and 77.55%, respectively. *P. elliottii* forest was the main planted forest carbon sink, with a ratio of 98.99%.

### 3.2 Change of forest carbon density with forest age

We estimated carbon storage and density of the three studied forests and spatial distribution in study area via the parameter fitting method. We also investigated relationships between carbon density and ages of *P. massoniana*, *P. elliottii* and *C. lanceolata* (Fig. 2) using logistic equations. In this way, we estimated changes of carbon densities with time. Before they grew to mature, the carbon density of *P. elliottii* and *C. lanceolata* were close, and were both higher than that of *P. massoniana*. As forest age of the three species increased, their carbon sequestration ability was significantly enhanced.

### 3.3 Spatio-temporal dynamics of forest carbon density

Through regression analysis of forest carbon density with forest age, we calculated annual carbon storage of forest vegetation from 1985–2003. Total carbon density of the three studied forests increased yearly from 1985 to 2003 (Fig. 3). Carbon density increased from 33.78 Mg C/ha to 37.66 Mg C/ha during 1985–1994 and carbon storage increased by 6.50 Tg C. Afforestation projects contributed significantly to the increase in carbon storage, with enlargement in stand areas by $1.576 \times 10^5$ ha. Carbon density increased from 37.66 Mg C/ha to 42.36 Mg C/ha from 1994–2003 and carbon storage increased by 1.66 Tg C. As stand age increased, so did carbon sequestration capacity.

Carbon density of Taihe County was higher in the east and west, and lower in the middle. The carbon density of Xingguo County was higher in the northeast and lower in the middle (Fig. 4). With the progress of afforestation project, carbon storage of the three studied species in 2003 was 2.66 times greater than that in 1985, and carbon density increased 8.58 Mg C/ha over the study period. Afforestation substantially increased stand area, carbon storage and carbon density.

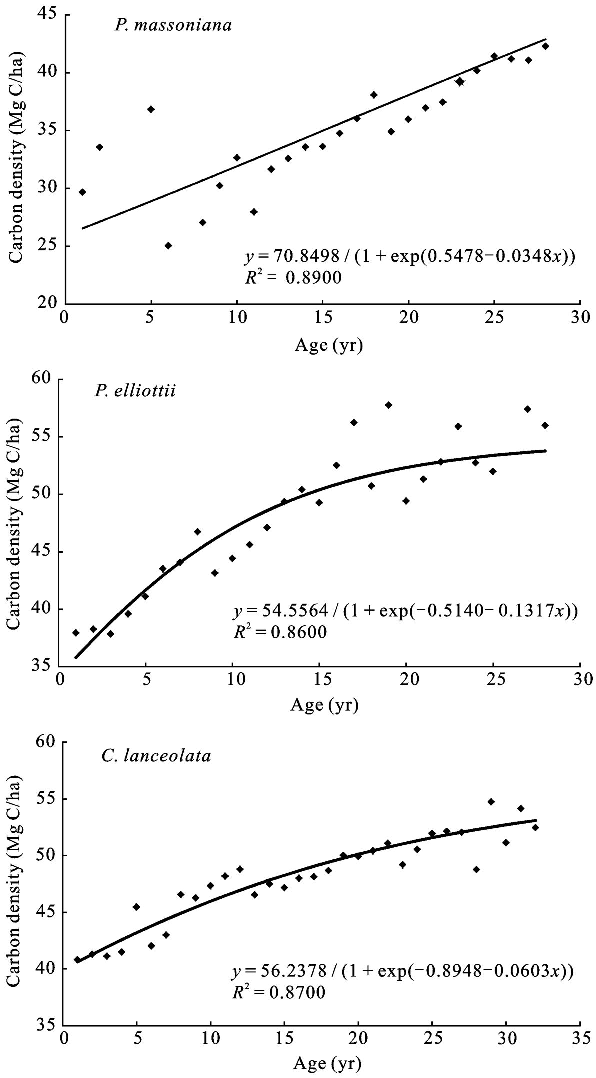


**Fig. 2** Relationships between forest carbon density and stand age for three studied forests in study area

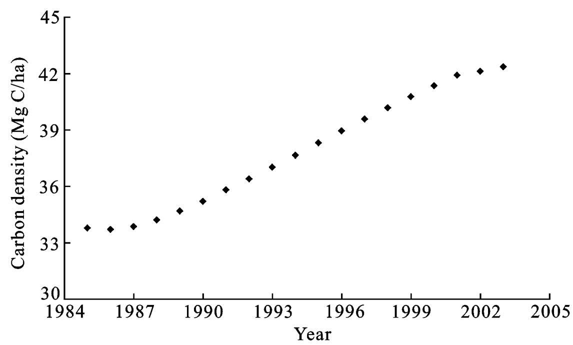


**Fig. 3** Changes of carbon densities for three studied forests in study area from 1985 to 2003

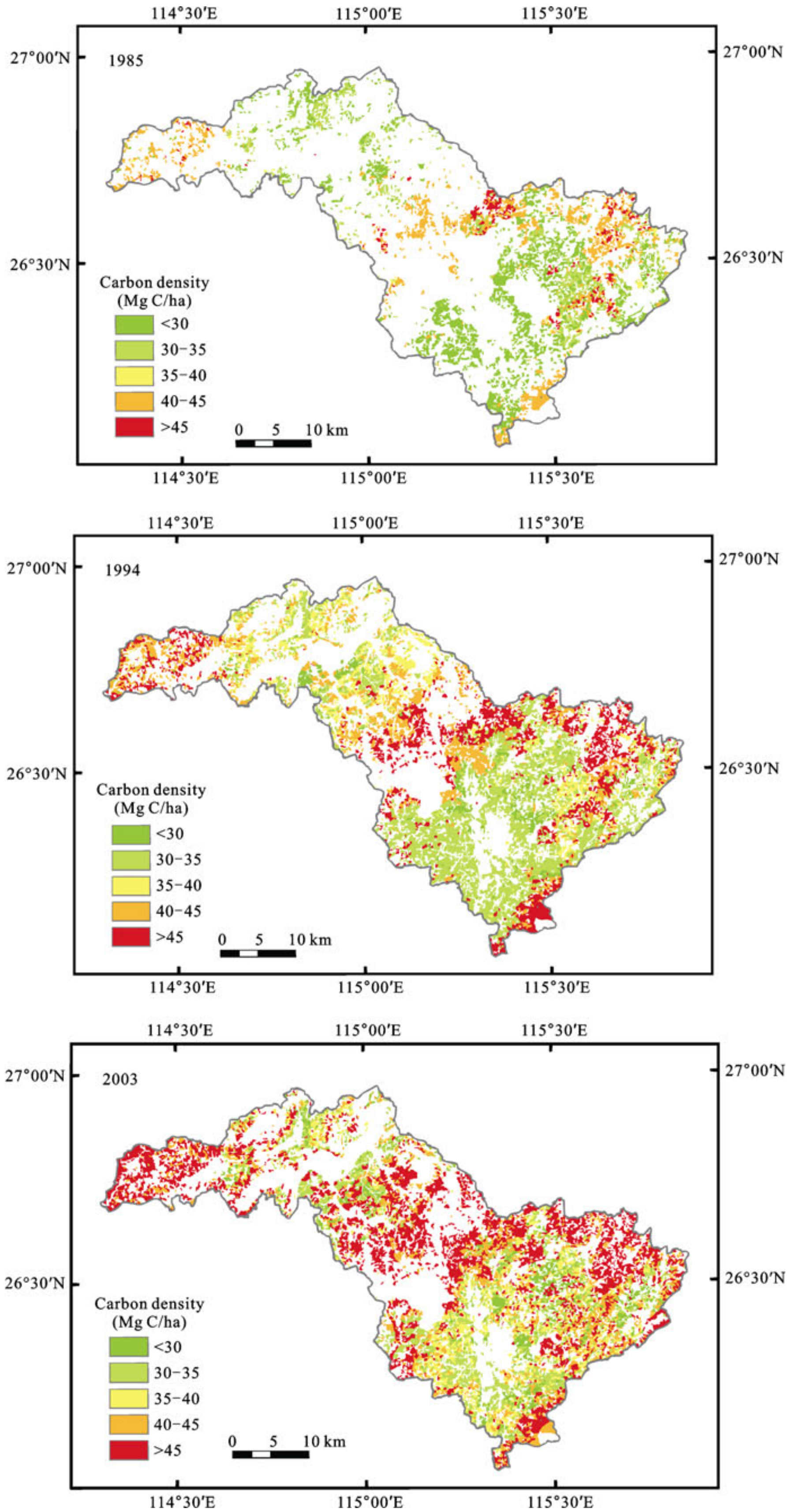


**Fig. 4** Spatial distribution of carbon densities for three studied forests of study area in different years

### 3.4 Change of forest carbon density with topography

We analyzed the effects of different altitudes and gradients on forest carbon density. According to the topography of the Boyang Lake Basin, we divided altitude into six categories: ≤100 m, 100–300 m, 300–500 m, 500–700 m, 700–900 m, and >900 m. Also, according to implemented regulations of the forest inventory, we defined six categories of gradient: 0°–5°, 5°–15°, 15°–25°, 25°–35°, 35°–45°, and > 45°.

Overall, carbon density of forest increased with altitude and gradient (Table 9). The highest average carbon density was between 700 m and 900 m, while the lowest density was below 100 m. The highest average carbon density was at slopes from 25° to 35° and the lowest was at slopes less than 5°.

**Table 9** Forest carbon density of different altitudes and slopes in study area

| Altitude (m) | Carbon density (Mg C/ha) | Slope (°) | Carbon density (Mg C/ha) |
|---|---|---|---|
| ≤100 | 40.97 | ≤5 | 40.46 |
| 100–300 | 41.02 | 5–15 | 42.29 |
| 300–500 | 42.99 | 15–25 | 44.09 |
| 500–700 | 45.54 | 25–35 | 44.75 |
| 700–900 | 47.30 | 35–45 | 44.18 |
| >900 | 46.71 | >45 | 44.39 |

## 4 Discussion and Conclusions

Carbon density (42.36 Mg C/ha) of the study area was higher than the average of Jiangxi Province (25.38 Mg C/ha) (Wei *et al.*, 2008). This has a certain role in the carbon reserve of the Boyang Lake Basin. Also, the carbon density was close to the national average from other research results, with the amounts of 41 Mg C/ha and 44.91 Mg C/ha (Fang *et al.*, 2001; Zhao and Zhou, 2004). Afforestation converts grassland or farmland into forest plantations, which can greatly increase forest carbon storage and carbon sink capacity. Since the stands of planted forests in the study area are mainly young or middle-aged, if combined with better tending and management, there is great potential for increased carbon sequestration.

We digitized forest subcompartment data. Although this represented substantial work, estimation of carbon storage and carbon density of forest vegetation was more efficient. Furthermore, it was possible to map the spatial distribution of carbon density, which can support forest planning, management and operation.

Although we estimated carbon storage of the three studied species, we did not consider the carbon pool of other species and the soil carbon pool. Further study could focus on the carbon reservoirs of other species and soil, for estimating the carbon fixation potential of the entire forest ecosystem.

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