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RESEARCH ARTICLE

Forest carbon sequestration in China and its benefits

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Carbon sequestration is important in studying global carbon cycle and budget. Here, we used the National Forest Resource Inventory data for China collected from 2004 to 2008 and forest biomass and soil carbon storage data obtained from direct field measurements to estimate carbon (C) sequestration rate and benefit keeping C out of the atmosphere in forest ecosystems and their spatial distributions. Between 2004 and 2008, forests sequestered on average 0.36 Pg C yr^{-1} (1 Pg = 10^{15}g), with 0.30 Pg C yr^{-1} in vegetation and 0.06 Pg C yr^{-1} in 0–1 meter soil. Under the different forest categories, total C sequestration rate ranged from 0.02 in bamboo forest to 0.11 Pg C yr^{-1} in broadleaf forest. The southwest region had highest C sequestration rate, 30% of total C sequestration, followed by the northeast and south central regions. The C sequestration in the forest ecosystem could offset about 21% of the annual C emissions in China over the same period, especially in provinces of Tibet, Guangxi, and Yunnan, and the benefit was similar to most Annex I countries. These results show that forests play an important role in reducing the increase in atmospheric carbon dioxide in China, and forest C sequestration are closely related to forest area, tree species composition, and site conditions.

Keywords: carbon sequestration; per unit area carbon sequestration; vegetation carbon sequestration; soil carbon sequestration; spatial distribution

1. Introduction

With the climate change debate advancing, various countries are exploring ways and means for responsibility and goal of energy conservation and emission reduction. Carbon (C) sequestration in forests has been shown to be a cost-effective option for mitigation of anthropogenic carbon dioxide (CO_2) emissions (Brown et al. 1996). The term "C sequestration" in forests is commonly used to describe any increase in biomass and soil C storage caused by a change in forest ecosystems. In 1990, estimated global forest ecosystems were estimated to be a net C source with emissions, ranging from 0.5 to 1.3 Pg C yr^{-1} (1Pg=10^{15}g) (Dixon et al. 1994). In contrast, recent global C analyses have estimated a global net forest C sink in the range from 1.0 ± 0.8 Pg C $yr^{-1}$for 1990–1999 to 1.2 ± 0.9 Pg C yr^{-1} for 2000–2007 based on forest inventory data and long-term ecosystem C studies (Pan et al. 2011). The change of C sequestration in global forests was consistent with estimated C sink of global terrestrial ecosystems, which increased from 1.0–2.6 Pg C yr^{-1} for the 1990s to, currently, 2.0–3.4 Pg C yr^{-1} (Watson et al. 2000; Canadell et al. 2007). These uncertainties have emerged and invoke multiple processes with strong spatial and temporal dynamics of global C sequestration.

Large-scale afforestation and reforestation have been proposed as a strategy for increasing C sequestration (Brown et al. 1996; Canadell et al. 2007). China has initiated a nationwide afforestation strategy since the 1970s (Wang et al. 2004), and the area of forest plantations has exceeded 60 million hectares (Mha), becoming first in the world (Jia 2009). Though not required by the Kyoto Protocol, China has planned to reduce C emissions and determine how to increase the country's C sequestration will be an important issue in regional C budgets (Liu & Diamond 2005). The most recent Chinese forest inventory data also showed that the area of forests in 2004–2008 has increased by 20.6 Mha over the past five years (Jia 2009). Policy-makers require more accurate information on the current and projected C sequestration in forests to make better plans for mitigating the climate change.

In recent years, major efforts have been made to estimate C sequestration rates of Chinese forests at a national scale, which ranged from 0.02 to 0.18 Pg C yr^{-1} (Xu 1999; RTCCCCS 1999; Fang et al. 2001; Zhang & Xu 2002, 2003). In spite of these efforts, it still remains a difficult task, surrounded by large uncertainties (Pan et al. 2011). The efficiency of C sequestration differs in different tree species as they vary in growth, mortality, and decomposition that drive C sequestration (Lorenz & Lal 2010; Wang et al. 2010). The C sequestration is also related to region, growing stage, and forest management activities (Johnson & Sharpe 1983; Turner & Lambert

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2000). However, forest type, region, and age classes were not taken into account in most previous estimates of C sequestration (Fang et al. 2001; Zhang & Xu 2002). It is, therefore, necessary to re-estimate the current forest C sequestration, using the newest data (2004–2008) and the direct field measurements. Additionally, relatively few studies have attempted to quantify the value of C sequestration via afforestation in China. The objectives for this study were to (1) quantify C sequestration (Pg C yr^{-1}) and its benefits to Chinese forest ecosystems in the period of 2004–2008; (2) analyze distribution of C sinks in different regions; and (3) understand how the composition and structure of forests affected forest C sequestration.

2. Materials and methods

2.1. C sequestration estimate method

2.1.1. Vegetation C sequestration estimate method

Based on the fact that production of every 1 g dry organic matter can fix 1.63 g CO_2 as the photosynthesis equation shows (Guo et al. 2001; Xue & Tisdell 2001; Zeng et al. 2008), we can estimate the amount of atmospheric CO_2 fixation in vegetation. The equation is shown as follows:

$$M_{vcs_i} = 1.63 \sum_i S_i \times NPP_i$$

where M_{VCSi} is the vegetation C sequestration (Mg yr^{-1}) of the ith vegetation type; S_i and NPP_i are the area (hm^2) and net primary productivity (NPP) value (Mg hm^{-2} yr^{-1}) of the ith vegetation type.

Different plants have different NPP and C content. In this study, NPP was estimated using field measurements that depend on the type of plants and available measurements. The estimates for the biomass and C content followed the methods proposed by Fonseca et al. (2011). A nested plot design was used, measuring the various biomass components (aboveground, belowground, and litter layers) by age class as well as by forest type at provincial levels. For each of the biomass components that are described below, an approximately 1 kg field subsample was taken to the laboratory for C analyses. The NPP of a stand, i.e. the change of biomass between 2 years, was then estimated according to the number of trees in each sampling area. Lastly, the vegetation C stock and sequestration of each stand was calculated using above equation.

2.1.2. Soil carbon sequestration (SCS) estimate method

The vegetation type method (Post et al. 1985) was utilized to estimate SCS. Because the 0–1-meter layer was thought to include most of the soil organic carbon (SOC) in a soil column (Campbell et al. 2008), the calculations incorporate horizon data to 1-meter depth and SOC content at depths below 1 m is regarded as 0 g C kg^{-1}. Firstly, we calculated the soil organic carbon density (SOCD) in different soil horizons, which represented the weight of organic C in the 1 m^3 soil-cubic at the soil profile depth of 1 m. Second, because the SOCD varied with vegetation type, we transferred the SOCD of soil horizons into $SOCD_i$ of vegetation. Finally, the $SOCD_i$ was multiplied by the area of each vegetation type to estimate the amount of soil organic carbon storage (SOCS) over the region.

The equations of SOCS estimate are as follows:

$$\mathrm{SOCS} = SOCD_i \times A_i$$

$$SOCD_i = \sum_{j=1}^{n} C_j \times D_j \times H_j \times (1 - P_j)/100$$

where SOCS is soil organic carbon storage (kg); A_i is the area (m^2) of the ith vegetation type; $SOCD_i$ is the organic carbon storage per unit area (kg m^{-2}) at the profile of the ith vegetation type; C_j, D_j, H_j and P_j are the *SOC* content (g C kg^{-1}), the average soil bulk density (g cm^{-3}), the thickness (cm) and the volume fraction of the fraction >2 mm of the jth soil horizon; n is the number of horizons involved.

The SCS is commonly used to describe any increase in SOC content caused by a change in forest ecosystems. The relation of SCS estimate is as follows (Liu & Li 2012):

$$SCS = \frac{SOCS_y - SOCS_{y-t}}{t}$$

where *SOCSy* is SOCS (kg) of invertory time in the yth year, and *SOCSy-t* is SOCS (kg) of the inventory time in the (y-t)th year.

2.2. Scaling up

A challenge in the field of C accounting is the need to upscale measurements and observations from the level of unit area, patch or stand, up to landscapes, regions, and beyond (Medlyn et al. 2003). Spatial upscaling main issues, such as sample grain size, sample extent, nonlinearities, and growing stage, must be considered (Harmon 2001).

The issues were addressed in this study by the following steps. The changes of biomass (aboveground or total) are related to forest type (species), region (site quality), growing stage (age class), and forest management activities (Johnson & Sharpe 1983). To reduce heterogeneity of site condition, entire China is divided into 31 regions by provinces. According to National Forest Inventory Report of China (Anonymous 2010), Chinese forests were subdivided into four large forest categories: bamboo forest (e.g. *Phyllostachys pubescens* and other bamboo species), economic forest (e.g. *Camellia oleifera*, *Vernicia fordii*, and *Sapium sebiferum*, and

Eucommia ulmoides plantations) and shrub forest (e.g. *Rhododendron spp*., *Hippophae spp*., *Sabina procumbens*, *Sophora Davidii*, and *Sabina vulgaris*), other forest (refers to all other plantations and natural forests, including 46 dominant tree species). In each province, the forest category was stratified into forest types by tree species; each forest type was further subdivided into five age classes, including young, middle-aged, near-mature, mature, and over-mature. In total, forest inventory data were compiled from more than 250,000 permanent and temporary plots across China, and we established 7012 sample plots across 31 provinces, 4 forest category and 5 age classes in the study area based on forest inventory plots (Forestry Ministry of China 1983). Annual C sequestration for vegetation and soil pool were then summed over all provinces in China to derive a national estimate for each year.

On the basis of a clear difference in climate, geography, land use, and social economy, we divided the whole area into seven subregions: North Central (including Beijing, Hebei, Inner Mongolia, Shanxi, and Tianjin), Northeast (including Heilongjiang, Jilin, and Liaoning), Northwest (including Gansu, Ningxia, Qinghai, Shaanxi, and Xinjiang), Southeast (including Jiangsu, Shandong, Shanghai, and Zhejiang), Southwest (including Sichuan, Yunnan, Chongqing, Guizhou, and Tibet), Central (including Henan, Hunan, Hubei, Anhui, and Jiangxi) and South Central (including Guangdong, Guangxi, Hainan, and Fujian) (Figure 1).

2.3. Estimating C sequestration benefits of forests

Forests create social benefits by keeping the C out of the atmosphere. The benefits are difficult to observe directly but can be calculated by observation of compensatory costs to reveal its cost to society, or "shadow price" (Brainard et al. 2006). Two methods have been typically used to indirectly quantify the benefits of C sequestration by forests. The first method is calculating the monetary value using a C fixation price (Baral & Guha 2004). The afforestation cost is typically estimated as the total afforestation investments divided by the C sequestered by the forests (Xue & Tisdell 2001). However, the cost of sequestering C for afforestation or reforestation is uncertain, varying from \$0 Mg^{-1} C to \$300 Mg^{-1} C (Sedjo et al. 1995; Thompson et al. 1997; Jotzo & Michaelowa 2001). Thus, it is difficult to use this method for comparisons of C sequestration benefit in different regions due to no standard global price. The second method is estimating the effects of C sequestration by forests in offsetting C emissions from the combustion of fossil fuels (Zhao et al. 2010). Therefore, the C sequestration benefits of forests in China were evaluated based on the ratio of the total C sequestered by forests to the total C emissions from the fossil fuels combustion. The annual average C emissions in China between 2005 and 2007 were derived from Yue et al. (2010).

3. Results

3.1. Chinese forest resources

According to the latest forest inventory data, China has 195.5 Mha of forests, or 20% of the total area of the country's land (Anonymous 2010). The volume of trees is estimated to be 14913 Mm^3 of which 13721 Mm^3 is in forests. Furthermore, Chinese forests account for 4.9% of the global forest area (4000 Mha) (FAO 2010) and

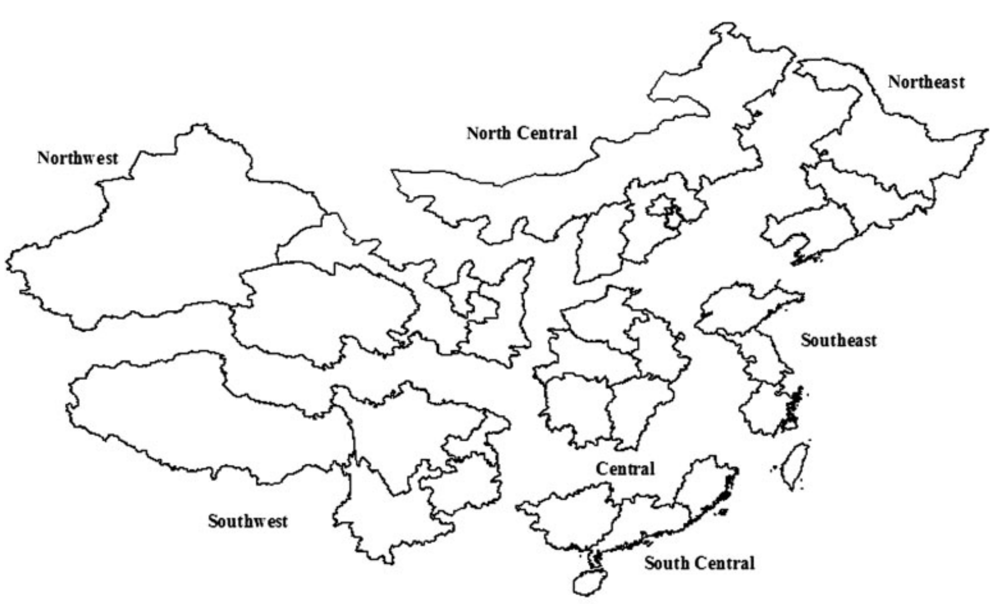

Figure 1. Zoning of China for calculation of C sequestration in forest ecosystems.

have 61.7 Mha of plantations with a stand volume of up to 1960 Mm^3, which is the largest of any country in the world.

The Orher Forest was the dominant forest category in Chinese forests, accounting for more than half of the total area of forests, followed by economic forests, shrub forests, and bamboo forests (Table 1). Forest was largely natural and mainly situated in southwest, northeast, and central regions. The southern provinces are home to predominantly plantations and bamboo forests. In terms of age-class distribution, the country's forest is heavily skewed toward the young and middle-aged forests (Table 2), particularly plantations. So they have a potential to sequester C due to high NPP per unit area and reduce atmosphere CO_2, even improving environment quality.

3.2. Forest C sequestration

The C sequestration rate of forest ecosystems in China was estimated to be 0.36 Pg C yr^{-1} from 2004 to 2008, with 0.30 Pg C yr^{-1} (84%) in vegetation and 0.06 Pg C yr^{-1} (16%) in soil. The majority of the C was sequestered by other forests, among which C sequestration rate was highest in broadleaf forests (30.6%), with a mean value of up to 0.11 Pg C yr^{-1}; coniferous forests had the next highest C sequestration rate, followed by mixed forests (Table 3). Per unit area C sequestration was highest in the mixed forest. The shrub forests and the economic forests had lower C sequestration rates, 0.04 Pg C yr^{-1} and 0.02 Pg C yr^{-1}, respectively. The C sequestration in the bamboo forest was the lowest in forests, but the per unit area C sequestration rate was higher, next to that of the mixed forest.

C sequestration showed a spatial pattern with the distribution of forest resources (Figures 2 and 3). Of the total C sequestration rate in Chinese forests, 0.11 Pg C yr^{-1}, or 30%, was found in the southwest region, far more than in any other regions. The northeast region had more than 17% of total C sequestration rate and highest per unit area C sequestration rate. In the south central region, total C sequestration rate was similar as in the northeast region, but per unit area C sequestration rate was lower than that of the other regions. The north central, central, northwest, and southeast regions together accounted for only 36% of the total C sequestration rate.

3.3. C sequestration benefits of forests

Annual average C emissions from the combustion of fossil fuels in China were 1.7 Pg C yr^{-1} (Yue et al. 2010). More than 20% of these C emissions could be offset by C sequestration of forests (Figure 4). The C sequestration benefits were not distributed evenly across regions. The highest was 67.7% in the southwestern region. The northeastern and the south central regions were also more than the level of national C sequestration benefits (21.1%), the former was 32.7%, and the latter 39.6%. The benefits of C sequestration reduced net C emissions to reach near zero in Tibet, Guangxi, and Yunnan. In the provinces, such as Heilongjiang, Jiangxi, Sichuan, Qinghai, and Inner Mongolia, sequestered C by forests were almost half or even greater than half of C emissions. The benefits of C sequestration were less, or below 1%, in Shanghai, Jiangsu and Tianjin.

4. Discussion

4.1. Influence of forest types on C sequestration

We investigated the variation in C sequestration in Chinese forest ecosystems. The variations along forest type and geographical location were consistent with results from the US forest ecosystems (Birdsey 1992). C sequestration in forest ecosystems are primarily related to changes in C sequestration in vegetation due to its large C sequestration rate. The C sequestration through increase in the forest area by afforestation and reforestation had been supported (Laganière et al. 2010). It was found that the broadleaf forest and the coniferous forest have higher C sequestration rates than other forest types. Moreover, the efficiency in C sequestration differs among the tree species as they vary widely in properties

Table 1. Chinese forest resources during 2004–2008.

	Total		Plantations		Young and middle-aged	
Category	Area (10^6 ha)	% of total	Area (10^6 ha)	% of total	Area (10^6 ha)	% of total
Other forest	155.6	80	40.0	64	104.6	100
Broadleaf forest	58.3	30	14.3	23	40.0	39
Coniferous forest	58.7	30	21.8	35	37.0	35
Mixed forest	38.5	20	3.9	6	27.6	26
Bamboo forest	5.4	3	2.2	4		
Economic forest	20.4	10	19.5	32		
Shrub forest	14.1	7				
Forests	195.5	100	61.7	100	104.6	100

Table 2. Chinese forest resources by seven regions.

Region	Forests		Plantations		Young and middle-aged	
	Area (10^6 ha)	% of total	Area (10^6 ha)	% of total	Area (10^6 ha)	% of total
North central	27.7	14	4.9	12	3.3	11
Northeast	29.8	15	5.4	13	4.0	13
Northwest	19.8	10	1.7	4	1.3	4
Central	29.2	15	6.3	16	7.2	24
Southeast	6.5	4	3.4	9	2.8	9
Southwest	54.8	28	9.2	23	4.7	16
South central	27.7	14	9.1	23	7.0	23
Total	195.5	100	40.0	100	30.3	100

Table 3. C sequestration rates for forests from four forest categories. Other forest is subdivided into mixed forest, broadleaves forest and coniferous forest.

Category	Amount		Per unit area	
	C sequestration (Pg yr^{-1})	% relative of total	C sequestration (Mg ha^{-1} yr^{-1})	% relative of total
Other forest	0.29	80	2.15	141
Broadleaf forest	0.11	30	2.55	167
Coniferous forest	0.10	28	2.03	133
Mixed forest	0.08	22	2.68	175
Bamboo forest	0.01	3	2.65	173
Economic forest	0.02	11	1.30	85
Shrub forest	0.04	6	1.00	65
Forests	0.36	100	1.53	100

that drive C sequestration (Purves & Pacala 2008). Pérez-Cruzado et al. (2012) reported that C sequestration (biomass and soil) in the broadleaf forests (*Eucalyptus nitens* and *Eucalyptus globulus*) was more than that in the coniferous forests (*Pinus radiata*) in Europe. NPP and biomass are greater in the broadleaf forests than in the coniferous forests in China (Jiang et al. 1999). Thus, the broadleaf forest had the highest C sequestration in this study due to higher per unit area C sequestration, as a result of higher NPP and soil C sequestration. The highest per unit area C sequestration in the mixed forest could be attributed to the presence of the broadleaved species rather than to the mixture (i.e. diversity) per se. Tree species composition affected site conditions, tree biomass, forest soil development, and soil C stocks, which influenced the C sequestration potential of forests (Binkley & Menyailo 2005; Chiti et al. 2007; Purves & Pacala 2008).

4.2. Influence of site condition on C sequestration

Soil C stocks appeared to be strongly influenced by soil type or climate than by tree species at regional or national scales (Vesterdal et al. 2013). The different regions also showed differences in the C sequestration of forest in this study. The greatest C sequestration of forest occurred in the southwest region, where was one of the mainly concentrated regions of Chinese forest distribution, area accounted for more than 28% of the total of forest area, and there are higher vegetation C density due to abundant water and sunshine that can provide favorable conditions for plantations (Li et al. 2004). The northeast region, one of the important forest zones in China, had highest soil C density due to thick litter layer and low rates of decomposition, particularly in the large area of the native forests (Li et al. 2004), which should have contributed to the higher C sequestration. The south central region had generally similar C sequestration as the northeast region. This is mainly because the provincial government is paying a great attention to plantation in the south central region, especially in fastest growing economies of Guangdong Province (Qi 2002; Yang 2003); this region has the maximum percentage of fast-growing plantations in China (Anonymous 2010). The northwest and southeast regions contained lowest C sequestration because trees were few and small in the regions that were affected by the human and the climate (Li et al. 2004; Anonymous 2010). It suggested that the spatial distribution of C sequestration was positively correlated with combinations of many factors, including forest structure, climate character, and forest policy and management.

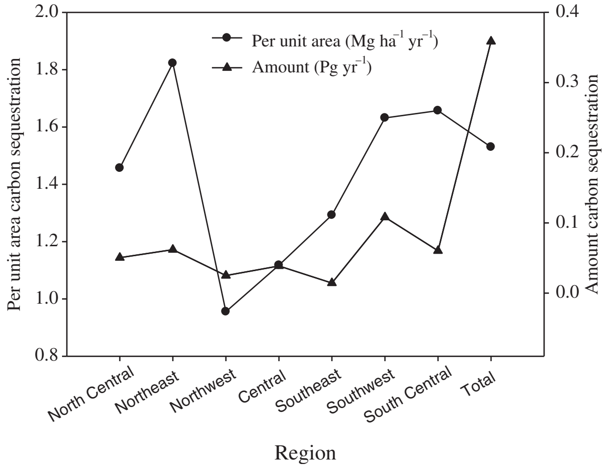

Figure 2. Carbon sequestration rates for forests in different regions.

4.3. Changes of C sequestration benefit

Based on the method for estimating the effects of C sequestration by forests in offsetting C emissions, our study showed that the benefits of C sequestration of forests in China (21.2% of C emissions) were lower than the average for global terrestrial ecosystems, which absorb about 30% of all CO_2 emissions from fossil fuel burning and net deforestation (Canadell et al. 2007), being especially high in New Zealand (81%), Sweden (62%), and Finland (56%). However, the figure for China was higher than for the USA (10%), Japan (7%), and Germany (3%) and most other Annex I countries (Woodbury et al. 2007). Owing to the uneven development of regional economy and forestry, the benefits of C sequestration in all the provinces were unequal. Tibet, Guangxi, and Yunnan provinces mostly achieved zero net C emission and C sequestration over C emission. The C sequestration was half of C emissions in some provinces, such as Heilongjiang, Jiangxi, Sichuan, Qinghai, and Inner Mongolia, but that declined to below 1% in Shanghai, Jiangsu, and Tianjin, suggesting that in these provinces, energy saving, and emission reduction plan are inevitable.

4.4. Comparison of C sequestration with previous estimates

The mean C sequestration rate of all major forest types in China, measured directly from field studies, was 0.36 Pg C yr^{-1}, which was much higher than those from previous estimates based on model, including that of Zhang and Xu (2003), Fang et al. (2001) and Pan et al. (2011), who shown were between 0.13 Pg C yr^{-1} and 0.18 Pg C yr^{-1} (Table 4). These differences could reflect changes in forest resources and estimate method. First, Chinese forests are constantly changing. With the changing needs of society and economy, the forests were cleared for urban and suburban development, highways, and agricultural use. Under the pressure of more natural disasters or negative impacts, Chinese government is paying a great attention to plantations and protection of natural forests. At present, the forest management policy to conserve forests can be grouped into four major categories: (1) maintained existing forest (stop deforestation and forest degradation), (2) agricultural land that was planted with trees or allowed to revert naturally to forest, (3) regenerated to forests in harvesting for timber products, and (4) introduce a massive afforestation and step up efforts for the fostering, protection, and management of forest resources. And, of course, all forest lands changed continually as trees and other vegetation naturally germinate, grow, and die.

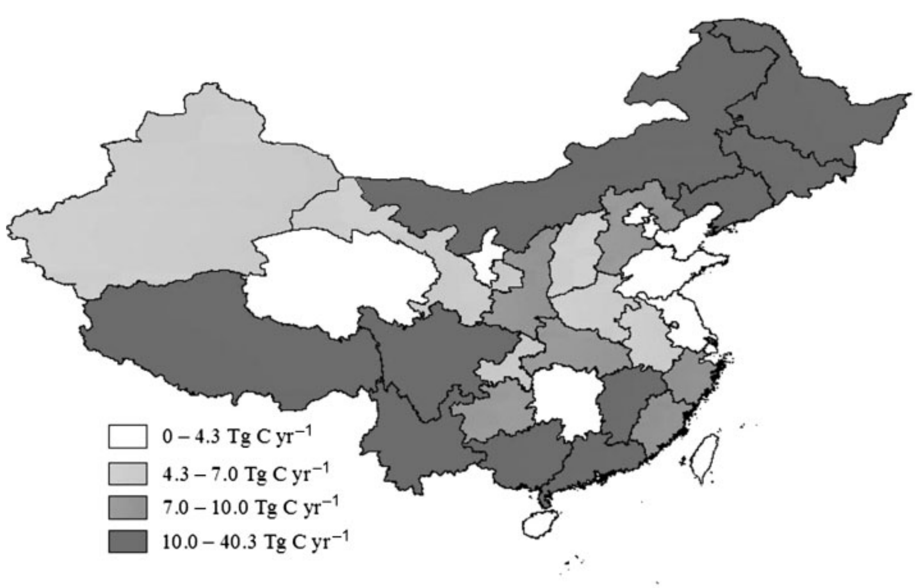

Figure 3. Carbon sequestration rates for forests from 31 provinces (1Tg = 10^{12}g).

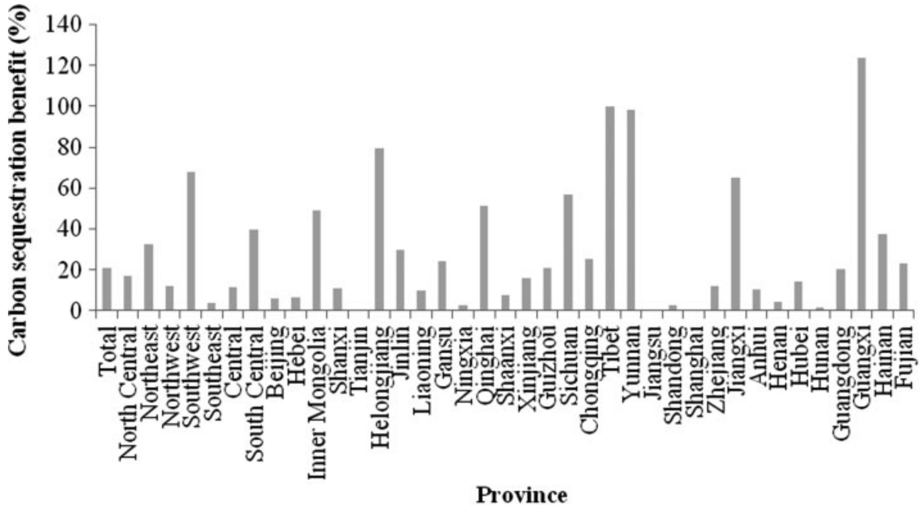

Figure 4. Carbon sequestration benefit for forests from 31 provinces.

Table 4. C sequestration rates of Chinese forests in different researches.

Period	Forest area (Mha)	Method	Carbon sequestration (Pg C yr^{-1})
2008–2012	155–185	Model	0.09–0.13 (Zhang & Xu 2003)
2000–2007		Model	0.18 (Pan et al. 2011)
1999–2003	142.8	Biomass expansion factor	0.18 (Fang et al. 2007; Piao et al. 2009)
2004–2008	195.5	Field measurement	0.36

C sequestration in different forest type, region, and age classes was not taken into account in most previous estimates (Zhang & Xu 2003). This study used the newest forest inventory data, and the area of total forest was higher than predicted values in Zhang and Xu (2003) and Fang et al. (2007), which led to a higher C sequestration. Compared with last five years, most young forests grew up, and the quality of forests had improved (Anonymous 2010). The size of the trees (DBH) affects C sequestration, and a large tree generally sequestered more C than a small tree (Nowak 1994). Finally, previous estimates depended largely on model projections and average point estimates. For example, the established regression model by Fang et al. (2001, 2007) was based only on stand volume of the mature forests, but ignored stand volume of the young and middle-aged forests. In contrast, our estimates used growth rate of stand data and was to scale C sequestration from the unit-area-level to the region-level in the case of considering spatial variability and integrate regional forest resources and C sequestration data to reach national comprehensive estimates.

4.5. Comparison of C sequestration with other countries

Forest covered an area of 195.5 million ha in China, about 4.9% of the world's forest area (FAO 2010), and contained 9% or less for the gross C sink (4.02 Pg C yr^{-1}) in the world from the atmosphere to vegetation and soil (Pan et al. 2011). In addition, the C sequestration of Chinese forests was close to that of the USA, but less than Russia and no less than those of other mid-to-high latitudes regions/nations' forests (Table 5). The value may be attributed to the largest plantations in China, and a high proportion of young and middle-aged forests. Plantations were effective in sequestering atmospheric CO_2 (Lal 2005; Turner et al. 2005; Schulze 2006). Young trees have great C sequestration potential and may respond to long-term CO_2 enrichment (Lorenz & Lal 2010). There may be another reason that the mission of C from burning, deforestation, and decay of vegetation is not estimated in this study.

Table 5. Forest C sequestration of China and selected main regions in the temperate zone.

Country	Carbon sequestration rate (Pg C yr^{-1})
Australia	0.04–0.06 (Pan et al. 2011)
Canada	0.01–0.08 (Stinson et al. 2011, Pan et al. 2011, Dixon et al. 1994)
USA	0.20–0.35 (Peter et al. 2007, Pan et al. 2011, Dixon et al. 1994)
Russia	0.30–0.80 (Lorenz & Lal 2010, Pan et al. 2011, Dixon et al. 1994)
Europe	0.09–0.30 (Pan et al. 2011, Dixon et al. 1994)
China	0.36

4.6. Concluding remarks

Forests play an important role in mitigating the impacts of climate change in China. The quantification of C sequestration by forests is critical for the assessment of the actual and potential role of forests in reducing atmospheric CO_2. This research provides a case study of the quantification of C sequestration by forests in China. Based on field survey data and forest inventory data derived in 2004–2008, it is estimated that Chinese forests vegetation sequestered five times C more than that in soil. The C sequestration by forests equaled to 21.2% of the annual C emissions from fossil fuel combustion in China. In addition, our results indicated that the C sequestration rate varied among forest types with different species composition and age structure, and there are significant regional differences due to the influence of site condition. Afforestation should be a common strategy that over the course of decades leads to the incorporation of C in plant biomass and soil. These results are important to support future climate mitigation actions, provide insights for decision-makers to make better management plans for forests at the regional, national, and global level.

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