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Updated estimation of forest biomass carbon pools in China, 1977–2018

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Abstract. China is the largest reforestation country in the world and the accurate estimation of its forest biomass carbon (C) pool is critical for evaluating the country's C budget and ecosystem services of forests. Although several studies have estimated China's forest biomass using national forest inventory data, most of them were limited to the period of 2004–2008. In this study, we extended our estimation to the most recent period of 2014–2018. Using datasets of eight inventory periods from 1977 to 2018 and the continuous biomass expansion factor method, we estimated that the total biomass C pool and average biomass C density of Chinese forests increased from 4717 Tg C (1 Tg = 10^{12} g) in the period of 1977–1981 to 7975 Tg C in the period of 2014–2018 and 38.2 Mg C ha^{-1} to 45.8 Mg C ha^{-1} (1 Mg = 10^{6} g), respectively, with a net increase of 3258 Tg C and an annual sink of 88.0 Tg C year^{-1}. Over the recent 10 years (2009–2018) the averaged national biomass C density and C sink showed a respective increase of 5.0 Mg C ha^{-1} and 91.5 Tg C year^{-1} much larger than those of 39.6 Mg C ha^{-1} and 63.3 Tg C year^{-1} in the period of 1977–2008. These pronouncing increases were largely attributed to afforestation practices, forest age growth, and environmental changes. Our results have documented the importance of ecological restoration practices and provided an essential basis for assessing ecosystem services and achieving Chinas C neu trality target.

Keywords: Forest biomass; C sink; C density; China; ecological restoration projects

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1. Introduction

Terrestrial ecosystems absorb approximately 30% of annual anthropogenic CO_2 emissions (Terrer et al., 2021). Forests, covering ~30% of the global land area (Fahey et al., 2010; Guo et al., 2013), play fundamental roles in global C balance and mitigating climate change (Pan et al., 2011; Harris et al., 2021). Globally, forests sequester large amounts of C in woody biomass and soils (Pugh et al., 2019). Thus, even small changes in the forest C pool should be considered profound feedback on climate change (He, 2012). Forest area in China ranks fifth globally, accounting for 5.51% of global total (National Forestry and Grasslands Administration, 2019). China's diverse climate conditions and forest types are unique for forest carbon cycle research (Fang et al., 2010). China's forests are generally young with low C density and have large areal proportion of afforestation and reforestation, implying great potential for C sequestration in the future (Xu et al., 2010; Zhao et al., 2019). Since the 1990s, numerous studies have investigated China's forest resources, C storage, and C sinks; however, most were limited to the period of 2004–2008 (e.g. Fang et al., 1996, 2001, 2007; Fang & Chen, 2001; Xu et al., 2010; Guo et al., 2013; Zhang et al., 2013; Li et al., 2015; Zhang et al., 2015). In these studies, the estimated C sinks of Chinas forest differed considerably among their dedicated periods, ranging from 21 to 99.1 Tg C $year^{-1}$ (Fang et al., 2001; Guo et al., 2013; Zhao et al., 2019). The differences might be attributed to the diverse methods utilise and data inconsistency. There are no consistent, comprehensive comparison studies available including forest census data after 2013 (the 8th National Forest Inventory) combined with previous nationwide survey data. Therefore, a continuously updated estimation of China's forest C pools and magnitudes of C sequestration will be of great importance.

In 2020, the Chinese government announced its promise for achieving carbon neutrality target by 2060. Sequestrating more C through afforestation, reforestation, and optimal forest management is the most important components of nature-based solutions to global warming mitigation, and have been an essential part of China's commitment (Yu et al., 2021). Accurately updating estimates of the forest biomass C pool and sink capacity are also crucial for Chinas aim of reducing greenhouse gas emissions (Xu et al., 2010) and in reaching national carbon neutrality.

Mean biomass density, biomass expansion factor (BEF), and remote sensing are three common methods for estimating large spatial-scale forest biomass carbon stocks (Guo et al., 2010; Zhang et al., 2013). Among these methods, the BEF method is considered the most reliable method for large-scale biomass C estimation (Fang et al., 1998; Fang & Wang, 2001; Guo et al., 2010; Zhang et al., 2021). Therefore, we used the BEF method to calculate forest biomass using eight national forest inventories compiled during the period 1977–2018. We specially focus on the changes in biomass C stocks in the most recent decade (the period of 2009–2018) and compared them with those in the earlier 30 years (1977 to 2008) to fill in the knowledge gaps in this decade.

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2. Methods

2.1 Data sources

Eight national forest inventory datasets compiled by the Chinese Ministry of Forestry Administration from 1977 to 2018 were used in this study. Forest (the dominant tree species of the forest groups) area, timber volume, forest age, and type were reported for all provinces. According to Fang (2000), five zonal forest types including cold-temperate coniferous, temperate coniferous, temperate deciduous broad-leaved, temperate/subtropical mixed, and evergreen broad-leaved are dominate tree species. To quantify age-related tree growth, forests were further divided into five sub-groups: young, middle-aged, pre-mature, mature, and over-mature. Forest area and C stocks were calculated for each province. Chongqing municipality, which was separated from Sichuan province in 1997, was merged into Sichuan here. The detailed data of Taiwan, Hong Kong, and Macau are missing from the inventory datasets; thus, the calculations did not account for these three regions.

2.2 Data correction

In the early national forest inventory, the criterion of forest classification was set by the crown density at 0.3. It was revised to 0.2 in 1994. We unified the criterion by adopting the power functions (Eqs. (1) and (2)) provided by Guo et al. (2013):

$$AREA_{0.2}=1.290\times AREA_{0.3}^{0.995} \quad (R^2=0.996) \tag{1}$$

$$CARBON_{0.2}=1.147\times CARBON_{0.3}^{0.996} \quad (R^2=0.996) \tag{2}$$

where $AREA_{0.2}$ and $AREA_{0.3}$ are the forest areas (10^4 ha) with a crown density of 0.2 and 0.3, respectively, and $CARBON_{0.2}$ and $CARBON_{0.3}$ are the biomass C pools (Tg C) with a crown density of 0.2 and 0.3, respectively.

2.3 Statistical analysis

Fang et al. (2001) used the first-order derivative formula to calculate BEF using ground survey data of forest volume [Eq. (3) and (4)]. This approach enabled upscaling estimates from field plots to a regional level. The stock volume density was calculated according to area and stock volume of each forest type and age group in each province, and then BEF was used to calculate biomass:

$$\mathrm{BEF}=a+b/x \tag{3}$$

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$$y = \text{BEF} \cdot V \tag{4}$$

where x, V are the stock volume and stock volume density of a forest type at a certain age, and a and b are BEF function coefficients. BEF is the biomass expansion factor, and y is the biomass of a forest type at a certain age. BEF coefficients in Eq.(3) were retrieved from previous studies (Fang et al., 1998, 2002; Fang & Wang, 2001) (Table A1). A constant C conversion factor of 0.5 was used to convert biomass into C (Fang et al., 2001).

3 Results

3.1 Forest biomass C pool and its changes

The total forest biomass C stock, averaged biomass C density, and the biomass C sink during 1977–2008 were 5447 Tg C, 39.6 Mg C ha^{-1}, and 63.3 Tg C year^{-1}, respectively (Table 1). The corresponding values were 7525 Tg C, 44.6 Mg C ha^{-1}, and 154.8 Tg C year^{-1}, respectively, during 2009–2018, making an increase C sink of 91.5 Tg C year^{-1} (Table 1). Compared with the forest biomass C pool during 1977–1981, it increased by 3258 Tg C (69.1%) during 2014–2018. In general, the C density of forest biomass increased by 7.61 Mg C ha^{-1} (19.9%) during 1977–2018 (Table 1, Figure 1). It should be noted that the forest area increased by 41.0% from 1.24×10^8 ha during 1977–1981 to 1.74×10^8 ha during 2014–2018 (Table 1). Accelerated expansion of area through afforestation and reforestation may lead to a large C sink of 180.2 Tg C year^{-1} in 2014–2018 (Table 1, Figure 1). In addition, the forest biomass C pool varied considerably across the different periods. It was found to have decreased by 2.9 Tg C year^{-1} over 1994–1998, which was thought to have been due to the decrease in area of natural forest from 1994–1998.

The biomass C pools of planted forests and natural forests increased significantly during the study (Table 2). The biomass C pool of planted forest increased from 250 Tg C during 1977–1981 to 1470 Tg C in 2014–2018. This indicated that biomass C sinks had an average of 33.0 Tg C year^{-1}. The biomass C density of planted forests increased from 15.6 Mg C ha^{-1} during 1977–1981 to 28.3 Mg C ha^{-1} during 2014–2018. For natural forests, the biomass C pool increased in most timesteps during the study periods. Especially in the past 10 years, the biomass C sink of natural forest has grown rapidly, indicating 100.8 Tg C year^{-1} during 2009–2013 and 128.1 Tg C year^{-1} during 2014–2018 (Table 2). From 1977 to 2018, the increase in biomass C pool of natural forests was 2037 Tg C, indicating C sinks of 55.1 Tg C year^{-1}

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on average.

Table 1 Forest area, biomass C pool, C density, and C sinks from 1977 to 2018

Period	Forest parameter			
	Area (10^4 ha)	C pool (Tg C)	C density (Mg C ha^{-1})	C sink (Tg C $year^{-1}$)
1977–1981	12350	4717	38.2	
1984–1988	13169	4885	37.1	23.9
1989–1993	13971	5402	38.7	103.5
1994–1998	13241	5388	40.7	-2.9
1999–2003	14279	5862	41.1	94.9
2004–2008	15559	6427	41.3	112.9
Average				
1977–2008	**13762**	**5447**	**39.6**	**63.3**
2009–2013	16349	7074	43.3	129.4
2014–2018	17409	7975	45.8	180.2
Average				
2009–2018	**16879**	**7525**	**44.6**	**154.8**
Overall change				
1977–2018	**5059**	**3258**	**7.61**	**88.0**

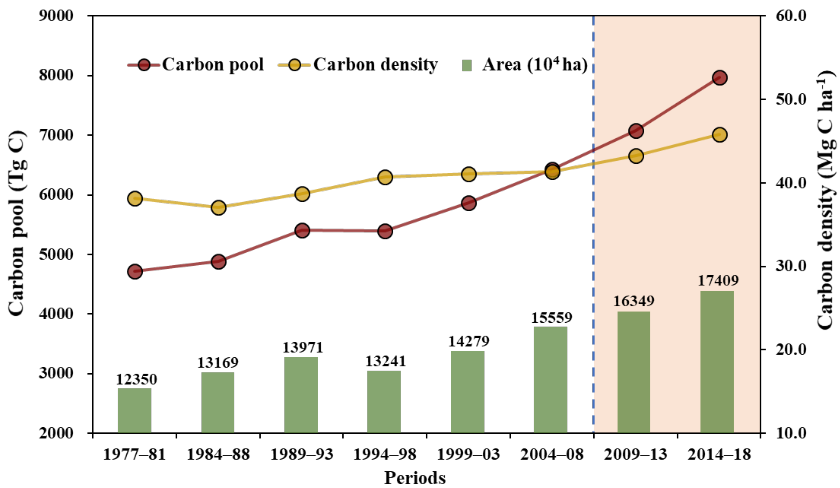

Figure 1 Changes in the area, biomass C pool, and C density of forests from 1977 to 2018. The pink box highlights the most recent results from the last ten years.

Table 2 Area, biomass C pool (CP), C density (CD), and C sinks (CS) of planted and natural forests

Period	Planted forest				Natural forest			
	Area 10^4 ha	CP Tg C	CD Mg C ha^{-1}	CS Tg C $year^{-1}$	Area 10^4 ha	CP Tg C	CD Mg C ha^{-1}	CS Tg C $year^{-1}$
1977–1981	1595	250	15.6		10755	4468	41.5	
1984–1988	2347	418	17.8	24.1	10822	4467	41.3	-0.1
1989–1993	2675	526	19.7	21.6	11296	4876	43.2	81.9
1994–1998	2914	642	22.0	23.3	10326	4746	46.0	-26.2
1999–2003	3229	836	25.9	38.7	11049	5026	45.5	56.2
2004–2008	4000	1067	26.7	46.2	11559	5360	46.4	66.7
2009–2013	**4665**	**1183**	**25.4**	**23.3**	**11685**	**5864**	**50.2**	**100.8**
2014–2018	**5193**	**1470**	**28.3**	**57.3**	**12212**	**6505**	**53.3**	**128.1**
1977–2018				**33.0**				**55.1**

3.2 Changes of biomass C pools in different zonal forest types

Compared with during1977–2008, areas of temperate coniferous forest, temperate deciduous broad-leaved forest and evergreen broad-leaved forest increased during 2009–2018. With the exception of the temperate deciduous broad-leaved forest, C sinks of four of the five forest types increased in the past 10 years (2009–2018) in comparison to 1977–2008 (Table 3). Particularly, the biomass C sink of evergreen broad-leaved forests during 2009–2018 was 84.6 Tg C $year^{-1}$, which is much higher than the average C sink for the previous 30 years (22.8 Tg C $year^{-1}$, 1977–2008). For more details about the area, C pool, C density and C sinks between 1977 and 2018, please refer to Table A2. There was an increase in area, biomass C density, with the biomass C pool remaining the same from 2009 to 2018. The C pool of the evergreen broad-leaved forest reached 2747 Tg C during 2014–2018 (Table 3, Table A2). Overall changes in the biomass C pools from 1977 to 2018 indicated that, with the exception of cold-temperate coniferous forests, the biomass C pools of four out of the five forest types all increased. The largest increase took place in the evergreen broad-leaved forest (1463 Tg C), which had an average annual C sink of 39.5 Tg C $year^{-1}$ (Table A2).

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Table 3 Area, biomass C pool (CP), C density (CD), and average C sinks (CS) of different zonal forest types in the recent decade compared to the previous 30 years*

Zonal forest types	Periods	Area 10^4 ha	CP Tg C	CD Mg C ha^{-1}	CS Tg C $year^{-1}$
Cold-temperate coniferous forest	1977–2008	2080	1461	70.2	-8.2
	2009–2018	1844	1321	71.6	11.3
Temperate coniferous forest	1977–2008	1125	381	33.9	9.9
	2009–2018	1740	652	37.5	13.7
Temperate deciduous broad-leaved forest	1977–2008	3614	1430	39.6	26.2
	2009–2018	3714	1730	46.6	19.5
Temperate/subtropical mixed forest	1977–2008	3989	975	24.4	12.6
	2009–2018	3834	1308	34.1	25.7
Evergreen broad-leaved forest	1977–2008	2953	1200	40.7	22.8
	2009–2018	5748	2515	43.7	84.6

* The average C sink for the previous 30years was calculated by dividing the difference between the 2004–2008 and 1977–1981 C pools by 27. The average C sink over the recent decade was calculated by dividing the difference between the 2014–2018 and 2004–2008 C pools by 10.

3.3 Biomass C sequestration in different forest age groups

In the original national forest inventory, only three age groups were recognised, namely young forests, middle-age forests, and old-age forests. In the subsequent inventories, forests were categorised into five different age groups. These were young, middle-age, pre-mature, mature, and over-mature forests. To ensure a consistent temporal comparison, the old growth forests from the first inventory were reclassified into pre-mature, mature, and over-mature forest groups.

The growth rate by area and C pool of all forest age groups over the last 10 years (2009–2018) was higher than for the previous 30 years (1977–2008). In addition, forest area and C pool for each age group reached the highest level recorded during 2014–2018. The area and C pool of old-aged forests were both the largest, at 6.33×10^7 ha and 4387 Tg C, respectively (Figure 2). The area of young, middle-aged, and old-aged forests increased from 1977 to 2018 by 1.47×10^7 ha, 1.08×10^7 ha, and 2.51×10^7 ha, respectively. Meanwhile, C pools increased by 657 Tg C, 791 Tg C, and 1810 Tg C, respectively. The biomass C densities of young, middle-aged, and old-aged forests increased by 7.9, 7.5, and 1.9 Mg C ha^{-1}, respectively.

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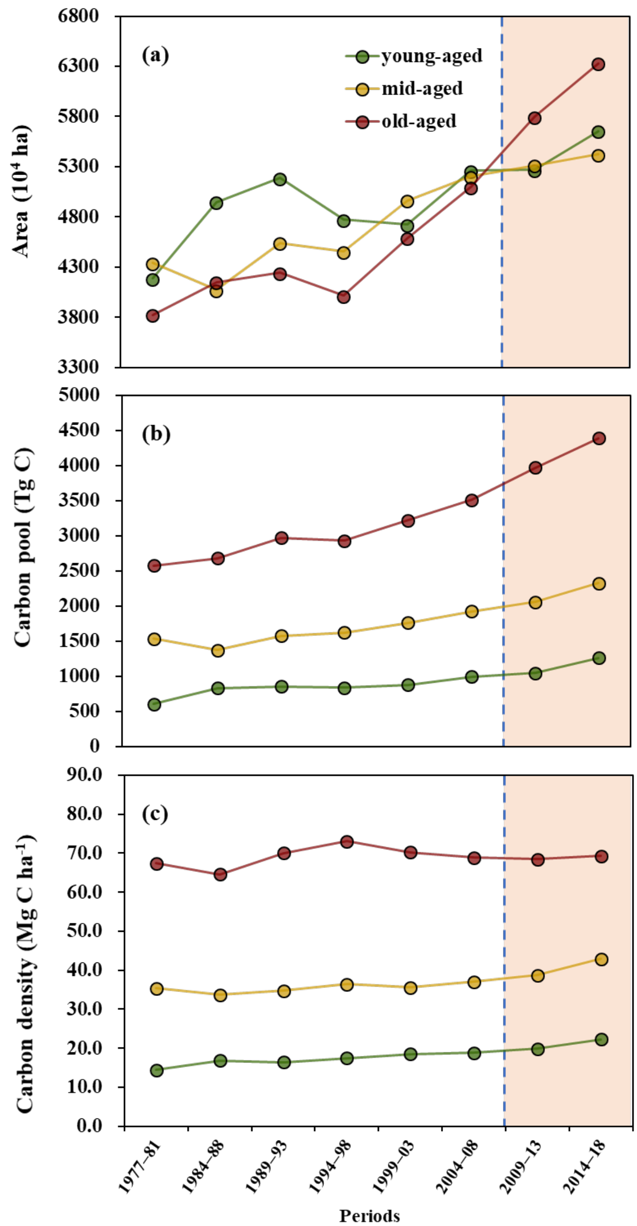

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160 **Figure 2** Changes in area (a), C pool (b) and C density of forest for each age group from 1977 to 2018.

161 The pink box highlights the latest results from the last ten years.

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4 Discussion

National forest inventories provide the most comprehensive spatial and temporal datasets for investigating forest change. Using data from eight forest inventories, this study provides an update on Chinas estimated forest biomass C, as well as obtaining the country 's forest biomass C pool and how it has varied over the last 40 years (1977–2018). This includes the most recent forest inventory period of 2014–2018. The estimated biomass C pool in this study is similar to the results reported by Zhang et al. (2015) and Zhao et al. (2021), lower than those by Fang et al. (2007), and higher than those by Zhang et al. (2021). Fang et al. (2007) determined a forest biomass C sink of 75.2 Tg C year^{-1} from 1977 to 2003, which is higher than the results found by this study (52.0 Tg C year^{-1}). This could be due to the linear relationship in the conversion process of crown density from 0.3 to 0.2 by Fang et al. (2007), but in this study the power functions (Eqs. (1) and (2)) relationship conversion were adopted. Zhang et al. (2021) did not use a unified standard for crown density (1977–1993), instead using data with crown density greater than or equal to 0.3, lowering the C pool results during the same period.

Results from the current study revealed that the latest forest biomass C pool (7975 Tg C, 2014–2018) was much larger than 4717 Tg C from 1977–1981, with an increase of 3258 Tg C (69.1%), and accordingly, the C sink averaged 88.0 Tg C year^{-1}. Since the late 1970s, China has launched six key national ecological restoration projects, including the Three-North Shelter Forest Program which initiative aims to protect the country's environment, as well as to restore degraded ecosystems (Lu et al., 2018). Through large-scale afforestation and reforestation projects, China now has the largest planted forest area in the world (Guo et al., 2013; Lu et al., 2018), which contributed 71.2% of total forest area expansion in China from 1977 to 2018 (Table 2). On the one hand, with these ecological restoration projects, management practices including forest enclosure, tending, and reduction of timber harvesting, have promoted the growth of natural forests (Xu et al., 2017; Fang et al., 2018; Lu et al., 2018). As a result, the area and biomass C pool of natural forests has increased greatly from 1.08 ×10^{8} ha and 4,468 Tg C during 1977–1981 to 1.22 ×10^{8} ha and 6,505 Tg C during 2014–2018, respectively. Moreover, the natural forest resource protection projects have prevented C loss from the vegetation and subsequently enhanced C stocks sinks, as well as allowing the area and biomass C pool of natural forests to increase (Xu et al., 2010; Fang et al., 2014a).

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On the other hand, large-scale plantation projects since the 1970s (Guo et al., 2013) have resulted in extensive forests reaching maturity. From 1977 to 2018, the area of middle- and old-age forests, and biomass C density of young and middle-aged forests has increased. Meaning, a large area of immature forest has there converted to reach the next age level for each period. The increase in biomass C density is an important factor for the growth of biomass C pools (Fang et al., 2014a). It is worth noting that biomass C density of old-aged forests has gradually stabilised over the last 10 years (2009–2018) (Figure 2). In addition to the death of trees due to natural disasters, the main reason for this decline may be the implementation of deforestation measures in old-aged forests. According to the 'Forest Law of the Peoples Republic of China ', mature forests are subject to reforestation after selective controlled selective cutting, thinning, and clearing of trees (Zhao et al., 2021). Several studies (Nabuurs et al., 2013; Coulstion et al., 2015; Harel et al., 2021) have found that ageing forests have a slowing C accumulation rate and a reduced change of C accumulation. Therefore, selective clearing and reforestation are more profitable for ways of improving levels of forest C sequestration (Nabuurs et al., 2013; Zhao et al., 2021).

In compared to the previous 30 years from 1977–2008, total forest area, biomass C stock, and averaged biomass C density increased tremendously in the last 10 years from 2009–2018, especially for C stock and C density. The C sink was 154.8 Tg C year^{-1} over the last 10 years, which was much higher than that of 63.3 Tg C year^{-1} during the previous 30 years. With a slowing down growth rate of forest area (Figure 1, Table 1), the increase in C density by the ongoing afforestation projects and forest growth has been an important driving factor for the rapid increase in C pool over the last decade from 2009–2018 (Zhao et al., 2021). The huge C sinks brought about by large-area forests with increased biomass C density should be an important source of power for Chinas forest C sinks after 2010 (Yu et al., 2021).

Historical environmental changes may be another important reason for promoting Chinas forest growth over the last decade. Owing to the use of fossil fuels and other human activities over the past few decades, China has experienced continuous increases in atmospheric CO_2 concentration and significant warming (Wei et al., 2009; Piao et al., 2010; Tian et al., 2011). From 1977 to 2018, the average annual change (2.29 ppm) in CO_2 concentration in China over the last ten years (2009–2018) is greater than that for the previous 30 years (1977–2008) (1.68 ppm; Global Montitoring Laboratory, https://www.gml.noaa.gov/). Elevated CO_2 concentrations strengthen C fertilisation in trees (Beedlow et

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al., 2004; Norby et al., 2005; Piao et al., 2009; Tian et al., 2011), which was one of the most important factors driving the long-term C sink in China (Pan et al., 2011). In addition, average annual temperatures for Chinese forest areas (11.3°C) over the last 10 years (2009–2018) were higher than those (10.8°C) from the previous 30 years (1977–2008; China Meteorological Data Service Center, https://data.cma.cn/data/index.html). The warming climate promotes biomass C accumulation both by accelerating photosynthesis and elongating growing seasons (Zhou et al., 2001; Piao et al., 2006; Fang et al., 2014b). This may also lead to an increase in the forest biomass C pool in China. In summary, expansion of Chinas forests (increasing area), forest growth (increasing C density), and environmental changes have contributed to the promotion of C sinks, particularly in recent decade (Fang et al., 2014a, b; Li et al., 2016; Zhao et al., 2019; Zhao et al., 2021).

The estimation involved in the study are presented with some uncertainties. In general, the national forest inventory data were assumed to have small errors of less than 5% (Fang et al., 2001). Survey accuracy of the forest area and timber volume was over 90% (National Forestry and Grasslands Administration, 2019). The method used to calculate biomass from surveyed stand volume data, and the R^2 of the BEF function (Eq. (3) and (4)) of the dominant tree species was higher than 0.80 (Table A1), suggesting our estimates of forest biomass were statistically reliable. Previous studies have shown estimate error of forest biomass at national scale using the BEF function are not likely to exceed 3% (Fang & Chen, 2001; Fang et al., 1996, 2002). Despite these uncertainties, the results of this study provide relatively high accuracy and a comprehensive assessment of the forest C budget.

5 Conclusion

In this study, we estimated forest biomass C storage and its changes in China over the past 40 years (1977–2018) and especially updated their estimates in the most recent decade (2009–2018), using the biomass expansion factor method and eight national forest inventories conducted every five years. We concluded that Chinese forest biomass C pool increased by 3258 Tg C with an annual C sink of 88.0 Tg C year^{-1} from 1977 to 2018. The biomass C pool and C sink in the last 10 years (7525 Tg C and 154.8 Tg C year^{-1}, 2009–2018) were much higher than those of the previous 30 years (5447 Tg C and 63.3 Tg C year^{-1}, 1977–2008), although the C sink strength displayed large variations in different periods.

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Expansion of forest area, forest growth, and environmental changes were proposed as the main drivers of this significant C increase especially in the recent decade. Our study updates the previous estimates of Chinas forest C storage and its changes and provides an essential basis for policy -making for ecosystem services and the carbon neutrality target in China.

Author contribution

JY Fang and C Yang designed the study and conducted the analysis, C Yang analysed the data and wrote the first draft, ZD Guo provided part of datasets, WJ Sun, JL Zhu, CJ J, YH Feng, SH Ma, Y Shi, and JY Fang revised the manuscript and gave final approval for publication.

Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Table A1 BEF function parameters of the main forest types in China[a] (Guo *et al* 2010)

Forest type	Function parameter: BEF=*a*+*b*/*x*				
	a	b	*n*	R^2	*P*
Picea、*Abies*	0.5519	48.861	24	0.7764	<0.001
Cunninghamia lanceolata	0.4652	19.141	90	0.9401	<0.001
Cupress	0.8893	7.3965	19	0.8711	<0.001
Larix	0.6096	33.806	34	0.8212	<0.001
Pinus koraiensis	0.5723	16.489	22	0.9326	<0.001
P. armandii	0.4581	32.666	10	0.7769	<0.001
P. massoniana, *P. yunnanensis*	0.5034	20.547	51	0.8676	<0.001
P. sylvestris var mongolica	1.112	2.6951	15	0.8478	<0.001
P.s tabuliformis	0.869	9.1212	112	0.9063	<0.001
Other pines and coniferous forests	0.5292	25.087	18	0.8622	<0.001
Tsuga, *Cryptomeria*, *Keteleeria*	0.3491	39.816	30	0.7899	<0.001
Mixed conifer-deciduous forest	0.8136	18.466	10	0.9953	<0.001
Betula	1.0687	10.237	9	0.7045	<0.001
Casuarina	0.7441	3.2377	10	0.9549	<0.001
Deciduous oaks	1.1453	8.547	12	0.9795	<0.001
Eucalyptus	0.8873	4.5539	20	0.802	<0.001
Lucidophyllous forests	0.9292	6.494	23	0.8259	<0.001
Mixed deciduous and *Sassafras*	0.9788	5.3764	32	0.9333	<0.001
Nonmerchantable woods	1.1783	5.5585	17	0.9483	<0.001
Populus	0.4969	26.973	13	0.9183	<0.001
Tropical forest	0.7975	0.4204	18	0.8715	<0.001

[a] where *a* and *b* are constants for a forest type and *x* (m^3 ha^{-1}) is mean timber volume per unit area, the unit of BEF is Mg m^{-3}; n is number of samples.

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381 **Table A2** Area, biomass C pool (CP), C density (CD) and C sink (CD) of different zonal forest types in
382 China

Zonal forest types	Period	Area 10^4 ha	CP Tg C	CD Mg C ha^{-1}	CS Tg C $year^{-1}$
Cold-temperate coniferous forest	1977–1981	2174	1463	67.3	
	1984–1988	2196	1481	67.4	2.6
	1989–1993	2350	1683	71.6	40.4
	1994–1998	2131	1637	76.8	-9.3
	1999–2003	1826	1263	69.2	-74.7
	2004–2008	1805	1242	68.8	-4.3
	2009–2013	1803	1287	71.4	8.9
	2014–2018	1885	1355	71.9	13.8
	1977–2018				**-2.9**
Temperate coniferous forest	1977–1981	837	284	33.9	
	1984–1988	1055	319	30.3	5.0
	1989–1993	1114	386	34.6	13.3
	1994–1998	1025	335	32.7	-10.2
	1999–2003	1144	410	35.8	15.0
	2004–2008	1573	552	35.1	28.4
	2009–2013	1707	616	36.1	12.9
	2014–2018	1773	689	38.8	14.5
	1977–2018				**10.9**
Temperate deciduous broad-leaved forest	1977–1981	2425	870	35.9	
	1984–1988	3793	1400	36.9	75.7
	1989–1993	4129	1539	37.3	27.8
	1994–1998	3694	1566	42.4	5.4
	1999–2003	3824	1626	42.5	11.8
	2004–2008	3820	1577	41.3	-9.7
	2009–2013	3838	1687	44.0	22.1
	2014–2018	3590	1772	49.4	17.0
	1977–2018				**24.4**
Temperate/subtropical mixed forest	1977–1981	3697	816	22.1	
	1984–1988	3459	703	20.3	-16.2
	1989–1993	4158	901	21.7	39.7
	1994–1998	4239	1016	24.0	23.1
	1999–2003	4528	1256	27.7	47.9
	2004–2008	3855	1156	30.0	-20.0
	2009–2013	3720	1203	32.3	9.4
	2014–2018	3948	1413	35.8	42.0
	1977–2018				**16.1**
Evergreen broad-leaved forest	1977–1981	3217	1284	39.9	
	1984–1988	2666	982	36.8	-43.2

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1989–1993	2221	893	40.2	-17.8
1994–1998	2151	834	38.8	-11.9
1999–2003	2956	1308	44.3	94.9
2004–2008	4506	1901	42.2	118.6
2009–2013	5282	2282	43.2	76.3
2014–2018	6213	2747	44.2	92.9
1977–2018				**39.5**