

Abstract

5 Forests play a leading role in regional and global terrestrial carbon (C) cycles. Changes in C sequestration within forests can be attributed to areal expansion (increase in forest area) and forest growth (increase in biomass density). Detailed assessment of the relative contributions of areal expansion and forest growth to C sinks is crucial to reveal the mechanisms that control forest C sinks and is helpful for developing sustainable forest management policies in the face of climate change. Using the Forest Identity concept and forest inventory data, this study quantified the spatial and temporal changes in the relative contributions of forest areal expansion and increased biomass growth to 10 China's forest C sinks from 1977 to 2008. Over the last 30 years, the areal expansion of forests was a larger contributor to C sinks than forest growth for all forests and planted forests in China (74.6 vs. 25.4 % for all forests, and 62.4 vs. 37.8 % for plantations). However, for natural forests, forest growth made a larger contribution than areal expansion (60.4 vs. 39.6 %). The relative contribution of forest growth of planted 15 forests showed an increasing trend from an initial 25.3 to 61.0 % in the later period of 1998 to 2003, but for natural forests, the relative contributions were variable without clear trends owing to the drastic changes in forest area and biomass density over the last 30 years. Our findings suggest that afforestation can continue to increase the C sink of China's forests in the future subject to persistently-increasing forest growth after 20 establishment of plantation.

1 Introduction

25 As the largest terrestrial ecosystem, forests occupy around 30 % of the global land surface area (Bonan, 2008; Pan et al., 2013) and play a dominant role in regional and global carbon (C) cycles because of their huge capacity for C storage and high productivity (Leith and Whittaker, 1975; Malhi et al., 2002; Pan et al., 2011). Forests can be sources of atmospheric CO₂ following anthropogenic and natural disturbances,

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but can also function as C sinks to sequester or conserve large quantities of C during regrowth after disturbances (Brown et al., 1996, 1999; Brown and Schroeder, 1999; Hu and Wang, 2008; Pan et al., 2011). Therefore, investigation of the possible mechanisms of forest C dynamics is of scientific and political importance (Watson et al., 2000; Fang et al., 2001, 2014a, b; Janssens et al., 2003; Nabuurs et al., 2003; Birdsey et al., 2006; McKinley et al., 2011).

China has the fifth-largest forest area of any country in the world (Ministry of Forest of China, 2009) and encompasses a variety of forest biomes, from boreal forests in the north to subtropical/tropical evergreen broadleaf forests in the south (Fang et al., 2010). With the implementation of national afforestation and reforestation programs since the late 1970s, such as the Three-north Protective Forest Program, the Natural Forest Conservation Program, and the Wetland Restoration Program, forest ecosystems in China are credited with making a significant contribution to regional and global C sinks in recent decades (Fang et al., 2001, 2014a; Fang and Chen, 2001; Lei, 2005; Xu et al., 2010; Pan et al., 2011; Guo et al., 2013). Based on the biomass expansion factor (BEF) method and China's forest inventory data, Guo et al. (2013) estimated the spatio-temporal changes in the forest biomass C sink from 1977 to 2008 and concluded that the annual biomass C sink ($70.2 \text{ Tg C yr}^{-1}$, $1 \text{ Tg} = 10^{12} \text{ g}$) offset 7.8% of the contemporary CO_2 emissions in the country.

In general, increased forest biomass C sinks are driven by forest areal expansion and forest regrowth. The Forest Identity concept, developed for separating the variables of change in forest area, biomass and C densities (Kauppi et al., 2006; Waggoner, 2008), is useful to developing the method estimating the change in forest biomass C stock driven by different causes. Using the Forest Identity concept, Shi et al. (2011) evaluated the status of change in China's forests and showed that the increase in C sequestration was attributable to the increase in forest area and growing stock density over the last three decades. More recently, to explore the mechanisms that drive forest C sinks in East Asia, Fang et al. (2014a) used the Forest Identity approach to estimate the relative contributions of changing forest area and forest C density to the forest biomass C sink

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in China, Japan and South Korea. These studies found that the relative contributions of the changing factors varied among countries and forest origin (planted vs. natural forests). Specifically, it was reported that forest areal expansion made a larger contribution to C sinks than increased biomass density for all forests. However, the study of Fang et al. (2014a) did not analyze the spatial and temporal variability in the relative contributions of forest areal expansion and increased biomass density to China's forest C sinks. In this study, we used the Forest Identity concept and forest inventory data to quantify in detail the spatial and temporal difference in the relative contributions of forest areal expansion and increased biomass density to China's forest C sinks during the past 30 years. Furthermore, we discussed the primary reasons for reduced biomass C stocks of natural forests in some provinces of China.

2 Data and methods

2.1 Forest inventory data

China's forest inventory data (CFID) for the periods 1977–1981, 1984–1988, 1989–1993, 1994–1998, 1999–2003, and 2004–2008 were used in this study (Chinese Ministry of Forestry, 1983, 1989, 1994, 2000, 2005, 2010). These inventories were compiled from more than 250 000 plots (160 000 permanent sample plots plus 90 000 temporary sample plots) across the country. Systematic sampling with a grid of 2 km by 2 km or 4 km by 4 km and an area of 10 m by 10 m was used depending on forest region. In CFID, China's forests were classified into three categories: stands (including natural and planted forests), economic forests (woods with the primary objective of production of fruits, edible oils, drinks, flavorings, industrial raw materials, and medicinal materials), and bamboo forests (Guo et al., 2013). In the present study, “forest” refers only to a “forest stand” with canopy coverage $\geq 20\%$ and therefore excludes economic and bamboo forests (Fang et al., 2007). For each forest type, the inventories documented detailed information on age class, area, and volume at the provincial level. To

3 Results

3.1 Spatial pattern of the relative contributions of forest area and biomass density to C sinks

Figure 1 shows the results of the national and regional relative contributions of forest areal expansion (a) and increased biomass C density (d) to the C sinks for all, planted, and natural forests between the late 1970s (1977–1981) and the 2000s (2004–2008). For all forests in China, the mean rates of change in forest area and biomass density were 0.85 and 0.29 % yr⁻¹, respectively, with a larger contribution by the former than that of the latter (74.6 vs. 25.4 %) to the net change of carbon stock (1709.7 Tg C) (Fig. 1a, Appendix Table A1). As shown in Fig. 1a, forest stands in all regions have increased in area and C density, and functioned as C sinks during the period 1977–2008 (also see Appendix Table A1), but the relative contributions differed considerably among regions. Within the Southwest, South Central and East regions, forest area increased remarkably, and thus areal expansion made a larger contribution than that of increased biomass density to the C sinks (the relative contributions of forest area in these regions were 89.6, 65.4, and 76.2 %, respectively). In addition, forest C sinks within these three regions were much larger than those of other regions in China (Appendix Table A1). The relative contributions of changes in forest area and biomass density were similar in the North (53.3 vs. 56.7 %) and Northwest (46.1 vs. 53.9 %) regions. However, in the Northeast region forest area increased only slightly, with a mean change of 0.06 % yr⁻¹, and thus made a small contribution (18.3 %) to the regional C sink over the past 30 years.

Planted forests have functioned as C sinks (817.6 Tg C) in the past three decades (Appendix Table B1), and areal expansion made a larger contribution to the C sink than did change in biomass density in all regions (Fig. 1b). At the national level, the area of planted forests increased at a mean rate of 3.18 % yr⁻¹ and contributed 62.2 % to biomass C sinks of planted forests between 1977 and 2008. Among the six regions, the largest contribution of areal expansion (78.2 %) was in the Southwest, followed by the

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expansion declined from 74.4 % between 1981 and 1988 to 39.0 % between 1998 and 2003, whereas the contribution of increased C density increased from 25.6 to 61.0 % over the same period (Fig. 2c). After 2003, on account of the rapid growth in forest area (Fig. 2a), the contribution of areal expansion increased and became the dominant contributor to the C sink of China's planted forest (87.7 vs. 12.3 % for 2003–2008).

In contrast to planted forest, the areal expansion and increase of C density in natural forests were more dynamic, having relatively lower rates of change less than 1.5 % yr⁻¹ over the study period (Fig. 2b). Furthermore, negative growth was observed in forest area ($a = -1.80\% \text{ yr}^{-1}$ for 1993–1998) and biomass C density ($d = -0.08$ and $-0.20\% \text{ yr}^{-1}$ for 1981–1988 and 1998–2003, respectively) in natural forest over the study period. Aligning with dynamic rates of change, the relative contribution of forest areal expansion showed a generally decreasing trend from 1981 (366.7 %) to 2008 (70.2 %), in contrast to the increase in C density (Fig. 2d). In addition, areal expansion always made a greater impact on the carbon sink than did the change in C density in most of the inventory periods, except for the period of 1988–1993, when increased C density made a slightly larger contribution than areal expansion (51.1 vs. 48.9 %).

3.3 Causes of C loss of natural forests at the provincial level

Over past three decades, planted forests have functioned as C sinks in all provinces of China (Appendix Table D1). However, three provinces showed a distinct C loss in their natural forests over the study period (Appendix Table E1): Heilongjiang (located in Northeast), Gansu (Northwest), and Fujian (East). Among these provinces, Heilongjiang contained the largest area of natural forest (1817.9×10^4 ha; 1977–1981) in China, of which the biomass C stock has shrunk by 47.2 TgC (783.7 TgC during 1977–1981 to 736.5 TgC in the 2000s). The C stocks of natural forest in Gansu and Fujian also underwent a decline from 87.0 and 132.8 TgC in the 1970s to 82.4 and 128.9 TgC in the 2000s, respectively. Here, we focused on these three provinces to explore the reasons for the declines in C stock of the natural forests over the past 30 years by quantifying the relative contributions of changes in forest area and C density.

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Among the three provinces, biomass C density of natural forests increased more or less from 1977 to 2008; the rate of change was highest in Gansu ($d = 0.66 \% \text{ yr}^{-1}$), whereas only slight increases were observed in Heilongjiang and Fujian (Fig. 3, Appendix Table E1). Conversely, the forest area in these provinces experienced more obvious decreases. The forest area in Heilongjiang decreased dramatically by $133.6 \times 10^4 \text{ ha}$ ($a = -0.28 \% \text{ yr}^{-1}$) over the last 30 years, followed by that of Gansu ($41.1 \times 10^4 \text{ ha}$, $a = -0.85 \% \text{ yr}^{-1}$) and Fujian ($12.9 \times 10^4 \text{ ha}$, $a = -0.14 \% \text{ yr}^{-1}$). Detailed analysis of the temporal dynamics of change rates in these provinces demonstrated that most of the decline in forest area occurred between 1981 and 1998 (Fig. 4a, c and e), whereas the contributions of forest area to the C stock change of these provinces increased rapidly, attaining their highest values (Fig. 4b, d and f). Overall, the rapid decline in forest area has exceeded the contribution of increased C density, and ultimately caused the C loss in these provinces (Figs. 3 and 4).

4 Discussion

4.1 Relative contributions of changes in forest area and biomass density to the C sink in China's forests

Over the past three decades, areal expansion and forest growth have increased C stocks in both planted (817.6 TgC) and natural (892.1 TgC) forests (Appendices B and C). However, the mechanisms underlying the C sinks differed markedly with various effects from these two driving agents.

For planted forests, areal expansion made a larger contribution than did biomass growth at both national and regional levels (Fig. 1b). Benefiting from the implementation of national afforestation and reforestation projects since the 1970s (Fang et al., 2001; Li, 2004; FAO, 2006; Wang et al., 2007), the area of planted forest in China has expanded dramatically from 16.95×10^6 to 24.05×10^6 ha over the last 30 years (Appendix Table B1). Meanwhile, the growth of these young forests also made a significant

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biomass density over the last 30 years (Fig. 2b), the relative contributions were variable without clear trends (Fig. 2d). For instance, in the period 1993–1998 biomass density increased from 43.2 to 46.0 Mg C ha⁻¹ ($d = 1.25 \% \text{ yr}^{-1}$), but forest area decreased by 0.97×10^6 ha ($a = -1.79 \% \text{ yr}^{-1}$) in the same period (Appendix Table C1, Fig. 2b). Thus, areal contraction was responsible for all of the C loss in the late 1990s. Analysis of C sinks at the provincial level also revealed that forest area declined at a relatively higher rate than the increase in biomass density in some provinces, making areal reduction the primary reason for C loss in natural forests (Fig. 3). Notably, since the late 1990s (1994–1998), natural forests in China have functioned as a persistent C sink, probably owing to implementation of the nationwide Natural Forest Conservation Project starting in 1998 (Appendix Table C1) (Shen, 2000; Lei, 2005; Ministry of Forestry of China, 2009; Guo, 2013). Subsequently, the relative contribution of changes in biomass has shown a constantly increase (Fig. 2d).

4.3 Uncertainty of estimates

Uncertainties in our studies mainly arise from the quality of forest area and timber volume data in the forest inventories and the estimation of national biomass stocks using the BEF method. On the one hand, precision in the forest area and timber volume data was required to be > 90 % in almost all provinces (> 85 % in Beijing, Shanghai, and Tianjin) (Xiao, 2005). On the other hand, the R^2 values of the BEF equations used to convert timber volume to biomass for most dominant tree species or forest types exceeded 0.8 (Fang et al., 2014a). Therefore, the data and method used in the present study show relatively high precision. Previous studies have reported that the estimation error of biomass stocks at the national level are expected to be less than 3 % in China (Fang et al., 1996).

5 Conclusions

With the implementations of national afforestation and reforestation programs since the late 1970s, China are credited with making a significant contribution to regional and global C sinks in recent decades. Used forest identity and CFID, this study quantified in detail the relative contributions of forest areal expansion and increased biomass density to China's forest C sinks during the past 30 years. Our findings suggested that the mechanisms underlying the C sinks for natural and planted forests differed markedly with various effects from these two driving agents. The areal expansion of forests was a larger contributor to C sinks than forest growth for all forests and planted forests while forest growth (e.g. increased biomass density) made a larger contribution for natural forests. Furthermore, the increasing trend in the relative contribution of forest growth to C sinks for planted forests highlight that afforestation can continue to increase the C sink of China's forests in the future subject to persistently-increasing forest growth after establishment of plantation.

Author contributions. P. Li and J. Zhu equally contributed to this work. J. Fang, J. Zhu, and P. Li designed the research; P. Li, J. Zhu, H. Hu, Z. Guo, and J. Fang performed the research; P. Li, J. Zhu, and J. Fang analyzed data; J. Fang, Y. Pan and R. Birdsey contributed new analytic tools; P. Li and J. Zhu prepared the manuscript with contributions from all co-authors.

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Table A1. Forest area, carbon stock, and carbon sinks for six regions in China from 1977 to 2008.

Period	China	North	Northeast	East	South Central	Southwest	Northwest
Area (10⁴ ha)							
1977–1981	12 350.3	1849.1	2953.9	1525.9	2173.3	2939.3	908.8
1984–1988	13 169.1	1899.8	3054.2	1723.2	2142.3	3333.0	1016.6
1989–1993	13 971.5	1997.1	3130.5	1904.2	2446.0	3532.6	961.2
1994–1998	13 240.6	1761.0	2769.8	1903.9	2498.8	3409.7	897.4
1999–2003	14 278.7	2003.3	2826.3	2026.7	2720.0	3802.2	900.3
2004–2008	15 559.0	2182.9	3000.7	2232.6	3087.3	4059.2	996.3
Net change	3208.7	333.9	46.8	706.7	914.0	1119.9	87.5
C stock (Tg C)							
1977–1981	4717.4	556.7	1249.9	384.5	456.4	1719.7	350.2
1984–1988	4884.8	593.6	1256.4	377.0	428.0	1857.3	372.6
1989–1993	5402.3	629.3	1308.7	428.8	505.4	2151.5	378.5
1994–1998	5387.9	621.3	1257.1	435.2	545.5	2145.4	383.5
1999–2003	5862.5	701.1	1272.8	515.7	653.0	2326.6	393.4
2004–2008	6427.1	760.1	1362.2	632.8	779.3	2465.3	427.4
Net change	1709.7	203.4	112.3	248.4	322.9	745.6	77.2
C density (Mg C ha⁻¹)							
1977–1981	38.2	30.1	42.3	25.2	21.0	58.5	38.5
1984–1988	37.1	31.2	41.1	21.9	20.0	55.7	36.6
1989–1993	38.7	31.5	41.8	22.5	20.7	60.9	39.4
1994–1998	40.7	35.3	45.4	22.9	21.8	62.9	42.7
1999–2003	41.1	35.0	45.0	25.4	24.0	61.2	43.7
2004–2008	41.3	34.8	45.4	28.3	25.2	60.7	42.9
Net change	3.1	4.7	3.1	3.1	4.2	2.2	4.4
C sink (Tg C yr⁻¹)							
1981–1988	23.9	5.3	0.9	-1.1	-4.1	19.6	3.2
1988–1993	103.5	7.2	10.5	10.4	15.5	58.8	1.2
1993–1998	-2.9	-1.6	-10.3	1.3	8.0	-1.2	1.0
1998–2003	94.9	16.0	3.1	16.1	21.5	36.2	2.0
2003–2008	112.9	11.8	17.9	23.4	25.3	27.8	6.8

Table B1. Forest area, carbon stock, and carbon sinks of planted forests for six regions in China from 1977 to 2008.

Period	China	North	Northeast	East	South Central	Southwest	Northwest
Area (10⁴ ha)							
1977–1981	1595.2	166.2	298.2	365.4	586.1	101.9	77.3
1984–1988	2347.2	244.7	497.8	583.0	595.9	277.1	148.7
1989–1993	2675.2	308.7	456.8	680.8	761.9	339.1	127.9
1994–1998	2914.4	309.5	474.4	717.5	878.5	396.7	137.9
1999–2003	3229.4	386.2	461.9	769.2	976.3	495.9	139.8
2004–2008	3999.9	494.4	536.6	928.8	1235.8	633.3	170.9
Net change	2404.6	328.2	238.3	563.4	649.6	531.4	93.6
C stock (Tg C)							
1977–1981	249.5	23.5	57.1	52.2	88.2	18.5	10.1
1984–1988	418.0	41.4	105.7	105.0	96.5	47.1	22.3
1989–1993	525.8	55.6	105.5	136.0	138.1	62.1	28.4
1994–1998	642.4	63.0	130.7	153.2	171.0	87.3	37.2
1999–2003	836.1	82.5	150.3	203.7	231.0	130.8	37.7
2004–2008	1067.1	104.8	179.9	261.4	299.0	173.0	49.1
Net change	817.6	81.4	122.8	209.2	210.8	154.5	39.0
C density (Mg C ha⁻¹)							
1977–1981	15.6	14.1	19.1	14.3	15.0	18.1	13.1
1984–1988	17.8	16.9	21.2	18.0	16.2	17.0	15.0
1989–1993	19.7	18.0	23.1	20.0	18.1	18.3	22.2
1994–1998	22.0	20.4	27.5	21.4	19.5	22.0	27.0
1999–2003	25.9	21.4	32.5	26.5	23.7	26.4	27.0
2004–2008	26.7	21.2	33.5	28.1	24.2	27.3	28.7
Net change	11.0	7.1	14.4	13.9	9.2	9.2	15.6
C sink (Tg C yr⁻¹)							
1981–1988	24.1	2.6	6.9	7.5	1.2	4.1	1.7
1988–1993	21.6	2.8	0.0	6.2	8.3	3.0	1.2
1993–1998	23.3	1.5	5.0	3.4	6.6	5.0	1.7
1998–2003	38.7	3.9	3.9	10.1	12.0	8.7	0.1
2003–2008	46.2	4.5	5.9	11.5	13.6	8.4	2.3

Table C1. Forest area, carbon stock, and carbon sinks of natural forests for six regions in China from 1977 to 2008.

Period	China	North	Northeast	East	South Central	Southwest	Northwest
Area (10⁴ ha)							
1977–1981	10 755.0	1682.8	2655.6	1160.5	1587.2	2837.3	831.5
1984–1988	10 822.0	1655.1	2556.5	1140.3	1546.4	3055.9	867.9
1989–1993	11 296.2	1688.3	2673.6	1223.3	1684.1	3193.5	833.3
1994–1998	10 326.1	1451.6	2295.5	1186.4	1620.3	3012.9	759.5
1999–2003	11 049.3	1617.0	2364.4	1257.5	1743.7	3306.2	760.4
2004–2008	11 559.1	1688.5	2464.1	1303.8	1851.5	3425.9	825.4
Net change	804.1	5.7	–191.5	143.2	264.3	588.5	–6.1
C stock (Tg C)							
1977–1981	4467.8	533.2	1192.8	332.3	368.2	1701.2	340.0
1984–1988	4466.8	552.2	1150.8	272.0	331.5	1810.2	350.3
1989–1993	4876.5	573.7	1203.2	292.8	367.3	2089.4	350.0
1994–1998	4745.5	558.3	1126.4	282.0	374.5	2058.0	346.3
1999–2003	5026.4	618.6	1122.5	311.9	422.0	2195.7	355.7
2004–2008	5360.0	655.3	1182.3	371.5	480.3	2292.3	378.3
Net change	892.1	122.0	–10.5	39.2	112.1	591.1	38.3
C density (Mg C ha⁻¹)							
1977–1981	41.5	31.7	44.9	28.6	23.2	60.0	40.9
1984–1988	41.3	33.4	45.0	23.9	21.4	59.2	40.4
1989–1993	43.2	34.0	45.0	23.9	21.8	65.4	42.0
1994–1998	46.0	38.5	49.1	23.8	23.1	68.3	45.6
1999–2003	45.5	38.3	47.5	24.8	24.2	66.4	46.8
2004–2008	46.4	38.8	48.0	28.5	25.9	66.9	45.8
Net change	4.8	7.1	3.1	–0.1	2.7	7.0	4.9
C sink (Tg C yr⁻¹)							
1981–1988	–0.1	2.7	–6.0	–8.6	–5.3	15.6	1.5
1988–1993	81.9	4.3	10.5	4.2	7.2	55.8	0.0
1993–1998	–26.2	–3.1	–15.4	–2.2	1.4	–6.3	–0.7
1998–2003	56.2	12.1	–0.8	6.0	9.5	27.5	1.9
2003–2008	66.7	7.3	12.0	11.9	11.7	19.3	4.5

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Table D1. Changes in forest area, carbon density, and carbon stock for planted forests in provinces of China for the period 1977–2008.

Province	Area (10 ⁴ ha)			Carbon density (Mg C ha ⁻¹)			Carbon stock (Tg C)		
	1977–1981	2003–2008	Net Change	1977–1981	2003–2008	Net Change	1977–1981	2003–2008	Net Change
Beijing	2.6	19.3	16.8	11.5	18.1	6.6	0.3	3.5	3.2
Tianjin	0.6	5.0	4.4	11.4	21.4	10.0	0.1	1.1	1.0
Hebei	43.1	122.2	79.0	12.5	20.7	8.2	5.4	25.3	19.9
Shanxi	12.5	57.2	44.7	13.2	21.9	8.7	1.6	12.5	10.9
Neimenggu	107.5	290.7	183.2	14.9	21.5	6.5	16.1	62.4	46.4
Liaoning	129.9	166.8	36.8	15.4	26.8	11.4	20.0	44.7	24.7
Jilin	88.1	141.5	53.3	21.6	39.7	18.1	19.0	56.1	37.2
Heilongjiang	80.2	228.4	148.2	22.6	34.6	12.0	18.1	79.0	60.9
Shanghai	0.0	3.4	3.4	0.0	16.9	16.9	0.0	0.6	0.6
Jiangsu	18.6	71.1	52.4	12.5	25.0	12.5	2.3	17.7	15.4
Zhejiang	63.5	118.5	55.1	12.6	24.6	12.0	8.0	29.2	21.2
Anhui	53.8	136.8	83.0	13.4	25.5	12.2	7.2	34.9	27.8
Fujian	108.6	239.8	131.2	18.8	37.3	18.4	20.5	89.4	68.9
Jiangxi	61.7	213.1	151.4	13.6	26.1	12.5	8.4	55.6	47.2
Shandong	59.2	146.0	86.8	9.9	23.3	13.4	5.9	34.0	28.1
Henan	37.7	164.6	126.9	12.7	25.4	12.8	4.8	41.9	37.1
Hubei	79.5	110.4	30.9	11.4	21.8	10.4	9.1	24.1	15.0
Hunan	115.5	290.8	175.3	13.1	25.4	12.2	15.2	73.8	58.6
Guangdong	183.8	343.5	159.7	14.9	20.0	5.1	27.3	68.5	41.2
Guangxi	148.7	293.1	144.4	19.6	28.1	8.5	29.1	82.4	53.3
Hainan	19.4	33.4	14.0	18.0	25.1	7.0	2.4	8.4	5.9
Sichuan	37.2	332.6	295.4	16.0	26.2	10.2	5.9	87.0	81.1
Guizhou	34.1	143.5	109.4	21.0	28.7	7.7	7.1	41.1	34.0
Yunnan	30.5	154.5	124.0	17.7	28.6	10.8	5.4	44.2	38.7
Xizang	0.2	2.8	2.6	0.0	24.4	24.4	0.0	0.7	0.7
Shanxi	33.2	77.1	43.8	12.8	21.1	8.3	4.3	16.3	12.0
Gansu	19.2	55.7	36.4	12.8	24.4	11.7	2.5	13.6	11.2
Qinghai	2.3	4.1	1.8	23.6	36.5	12.9	0.5	1.5	1.0
Ningxia	6.8	5.9	-0.9	12.2	21.3	9.1	0.8	1.3	0.4
Xinjiang	15.7	28.2	12.5	13.1	58.4	45.3		2.1	2.1

Bold font refers to the values in Hainan and Guangdong acquired from the forest inventory data in the period of 1984–1988, because these two provinces were not separated administratively until 1988 and their separate inventory data was lacked for the period of 1977–1981.

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Table E1. Changes in forest area, carbon density, and carbon stock for natural forests in provinces of China for the period 1977–2008.

Province	Area (10 ⁴ ha)			Carbon density (Mg C ha ⁻¹)			Carbon stock (Tg C)		
	1977–1981	2003–2008	Net Change	1977–1981	2003–2008	Net Change	1977–1981	2003–2008	Net Change
Beijing	5.8	16.2	10.4	15.5	17.9	2.4	0.9	2.9	2.0
Tianjin	0.5	0.4	-0.1	14.4	18.2	3.9	0.1	0.1	0.0
Hebei	103.0	166.1	63.0	16.1	17.5	1.3	16.6	29.0	12.4
Shanxi	77.1	115.2	38.1	27.2	28.5	1.3	21.0	32.8	11.9
Neimenggu	1496.3	1390.5	-105.8	33.1	42.5	9.4	494.7	590.4	95.8
Liaoning	172.6	194.6	22.0	29.3	35.2	5.9	50.6	68.6	18.0
Jilin	665.2	585.3	-79.9	53.9	64.5	10.5	358.6	377.2	18.7
Heilongjiang	1817.9	1684.3	-133.6	43.1	43.7	0.6	783.7	736.5	-47.2
Shanghai	0.2	0.0	-0.2	8.8	0.0	-8.8	0.0	0.0	0.0
Jiangsu	2.9	3.4	0.4	12.5	18.4	5.9	0.4	0.6	0.3
Zhejiang	227.7	275.1	47.4	19.2	21.5	2.3	43.8	59.2	15.4
Anhui	135.7	134.0	-1.7	20.4	25.2	4.8	27.6	33.8	6.1
Fujian	339.1	326.2	-12.9	39.2	39.5	0.4	132.8	128.9	-3.8
Jiangxi	442.0	555.0	113.0	28.7	26.6	-2.1	126.7	147.5	20.9
Shandong	12.9	10.1	-2.8	8.0	13.8	5.8	1.0	1.4	0.4
Henan	101.1	118.7	17.6	19.7	25.6	5.9	19.9	30.4	10.5
Hubei	317.9	397.4	79.5	18.4	23.1	4.7	58.6	91.8	33.2
Hunan	379.7	435.8	56.1	21.5	21.8	0.3	81.8	95.0	13.2
Guangdong	320.0	335.3	15.3	19.7	27.1	7.4	62.9	90.8	27.9
Guangxi	394.9	513.6	118.7	26.3	27.9	1.6	103.8	143.5	39.6
Hainan	49.5	50.7	1.3	49.4	56.7	7.3	24.4	28.8	4.3
Sichuan	765.8	1014.7	248.9	60.5	62.3	1.8	463.7	632.3	168.6
Guizhou	225.6	254.6	29.0	28.6	28.4	-0.1	64.5	72.4	7.9
Yunnan	1056.7	1318.2	261.5	52.2	53.4	1.2	551.2	703.6	152.4
Xizang	789.2	838.4	49.1	78.8	105.4	26.6	621.9	884.0	262.1
Shanxi	487.6	490.0	2.3	32.4	36.0	3.6	158.0	176.5	18.6
Gansu	198.9	157.8	-41.1	43.7	52.3	8.5	87.0	82.4	-4.5
Qinghai	21.9	31.4	9.6	41.9	52.1	10.2	9.2	16.4	7.2
Ningxia	4.1	5.2	1.1	22.6	31.3	8.7	0.9	1.6	0.7
Xinjiang	119.1	141.1	22.0	71.4	71.8	0.5	85.0	101.3	16.3

Bold font refers to the values in Hainan and Guangdong acquired from the forest inventory data in the period of 1984–1988, because these two provinces were not separated administratively until 1988 and their separate inventory data was lacked for the period of 1977–1981.

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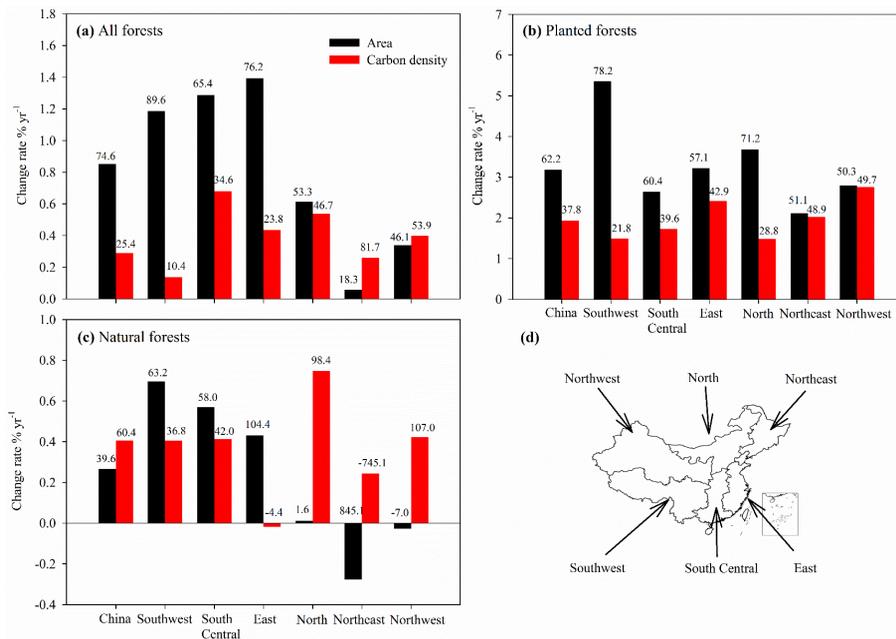


Figure 1. Rate of change and relative contributions of forest area and biomass density to carbon sinks in all (a), planted (b) and natural (c) forests in six broad regions of China for the period 1977–2008. The division of these six broad regions are indicated as (d). Bars and numbers above represent the change rates and their relative contributions of forest area (in black color) and carbon density (in red color), respectively.

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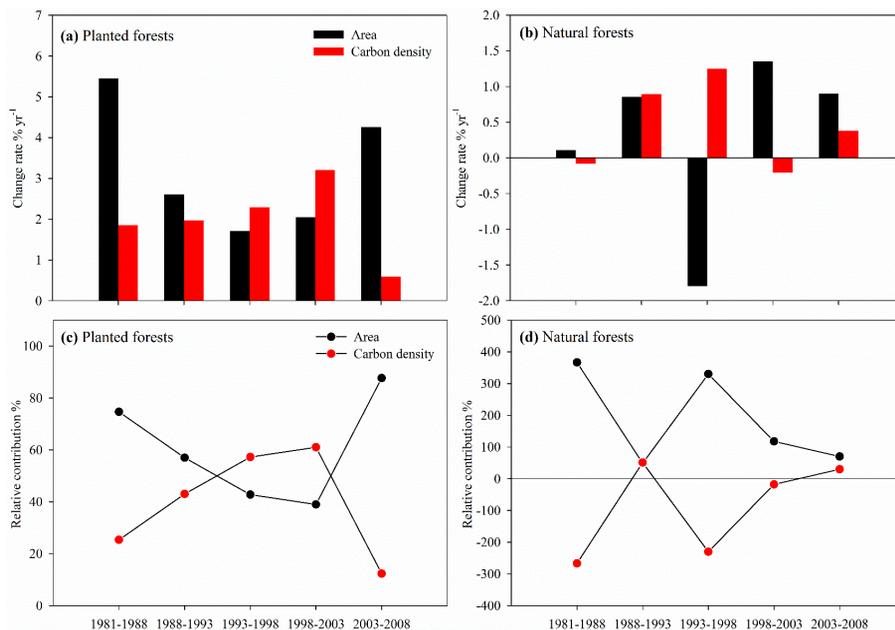


Figure 2. Relative contributions and the dynamics of areal expansion and forest growth to carbon sinks in planted (a and c) and natural (b and d) forests of China in the period 1977–2008. Bars and points represent the rates of change and relative contributions of forest area (in black color) and carbon density (in red color), respectively.

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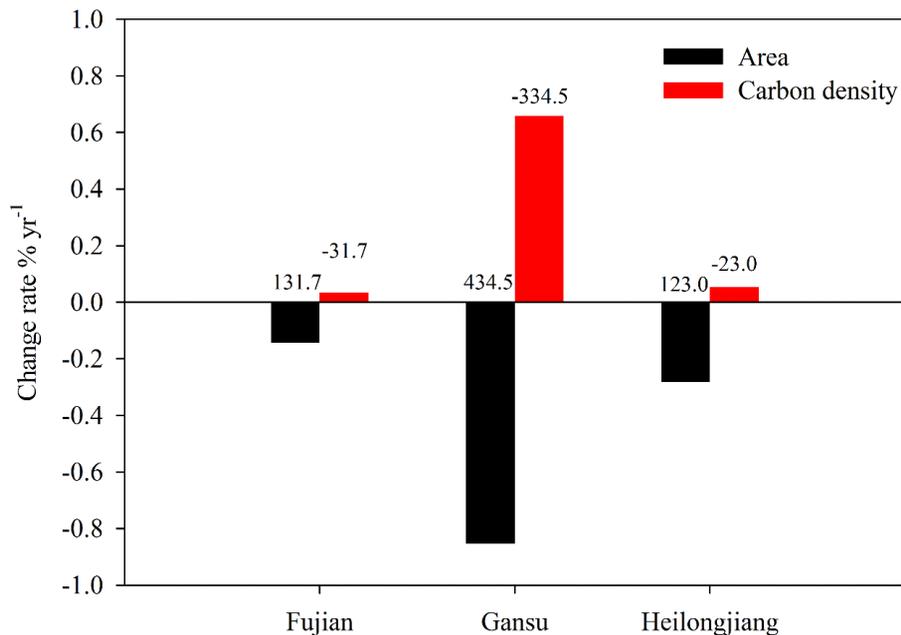


Figure 3. Rate of change and the relative contributions of changes in forest area and carbon density of natural forests to carbon loss in three provinces of China in the period 1977–2008. Bars and numbers above represent the change rates and their relative contributions of forest area (in black color) and carbon density (in red color), respectively.

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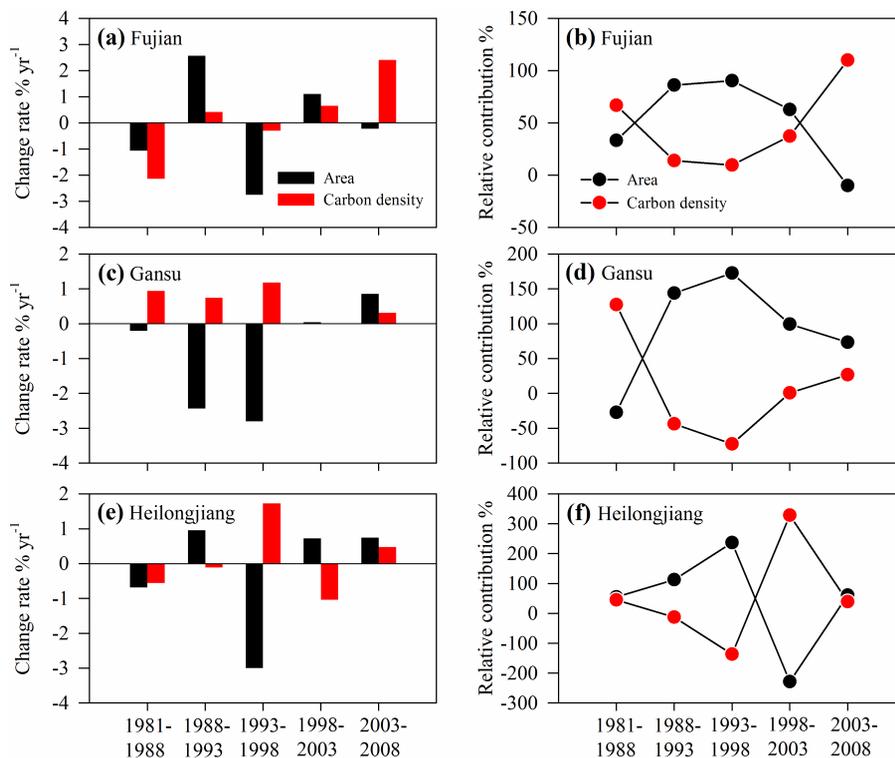


Figure 4. Rate of change (a, c and e) and relative contributions of changes (b, d and f) in forest area and carbon density of natural forests to carbon loss in three provinces of China in the period 1977–2008. Bars and points represent the rates of change and relative contributions of forest area (in black color) and carbon density (in red color), respectively.