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

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Supplementary Information

<u>**Contents:**</u>

Supplementary Methods

Data sources

Climatic variables (mean annual temperature, MAT, and mean annual precipitation, MAP) were interpolated from the monthly climatic records during 1982–2018 at 728 meteorological stations (National Meteorological Information Center of the China Meteorological Administration, http://www.nmic.gov.cn), with a spatial resolution of 0.083° using a Thin Plate Spline interpolation algorithm. Global Montitoring Laboratory, https://www.gml.noaa.gov/).Total inorganic (nitrate and ammonium) nitrogen deposition data was extracted from global nitrogen deposition data set (Eyring et al., 2013). CO_2 concentration data during 1977–2018 were obtained from Earth System Research Laboratories (Global Montitoring Laboratory, https://www.gml.noaa.gov/).

Statistical analysis

Taking environmental factors as independent variables and biomass carbon density as dependent variables, use R to perform a univariate linear regression:

$$C\ density = a + b \times Environmental\ factor \quad \text{(S1)}$$

where *a* is intercept, *b* is coefficient. *C density* is the average value of C density across different forest types and age-classes in each period. We used the simple average values instead of the area-weighted average values, in order to eliminating the potential influences of the changes in forest types and forest age-classes on the overall C density of forests. *Environmental factor* represents CO_2 concentration, mean annual temperature (MAT), mean annual precipitation (MAP) and total nitrogen (N) deposition.

Supplementary Tables

Table S1 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*	0.552	48.861	24	0.776	<0.001
Cunninghamia lanceolata	0.465	19.141	90	0.940	<0.001
Cupress	0.889	7.397	19	0.871	<0.001
Larix	0.610	33.806	34	0.821	<0.001
Pinus koraiensis	0.572	16.489	22	0.933	<0.001
P. armandii	0.458	32.666	10	0.777	<0.001
P. massoniana, *P. yunnanensis*	0.503	20.547	51	0.868	<0.001
P. sylvestris var mongolica	1.112	2.695	15	0.848	<0.001
P.s tabuliformis	0.869	9.121	112	0.906	<0.001
Other pines and coniferous forests	0.529	25.087	18	0.862	<0.001
Tsuga, *Cryptomeria*, *Keteleeria*	0.349	39.816	30	0.790	<0.001
Mixed conifer-deciduous forest	0.814	18.466	10	0.995	<0.001
Betula	1.069	10.237	9	0.705	<0.001
Casuarina	0.744	3.238	10	0.955	<0.001
Deciduous oaks	1.145	8.547	12	0.980	<0.001
Eucalyptus	0.887	4.554	20	0.802	<0.001
Lucidophyllous forests	0.929	6.494	23	0.826	<0.001
Mixed deciduous and *Sassafras*	0.979	5.376	32	0.933	<0.001
Nonmerchantable woods	1.178	5.559	17	0.948	<0.001
Populus	0.497	26.973	13	0.918	<0.001
Tropical forest	0.798	0.420	18	0.872	<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.

Table S2 Area, biomass C pool, C density and C sink of different zonal forest types in China

Zonal forest types	Period	Area 10^4 ha	C pool Tg C	C density Mg C ha^{-1}	C sink Tg C yr^{-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	1977–1981	3217	1284	39.9	

forest	1984–1988	2666	982	36.8	-43.2
	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**

Table S3 Forest area change and biomass C sink during 1977–2008 and 2009–2018 in each province

Province	1977–2008		2009–2018	
	Area change 10^4 ha	Carbon sink Tg C yr^{-1}	Area change 10^4 ha	Carbon sink Tg C yr^{-1}
China	3208.7	63.32	1849.9	154.80
Beijing	27.2	0.19	19.3	0.62
Tianjin	4.4	0.04	4.2	0.11
Hebei	142.0	1.19	30.9	2.43
Shanxi	82.8	0.84	60.6	2.38
Inner Mongolia	77.4	5.26	64.4	16.37
Liaoning	58.8	1.58	57.6	4.69
Jilin	-26.6	2.07	47.9	7.82
Heilongjiang	14.6	0.51	69.2	15.13
Shanghai	3.2	0.02	3.6	0.16
Jiangsu	52.9	0.58	51.8	1.42
Zhejiang	102.4	1.36	22.7	4.22
Anhui	81.3	1.25	32.0	3.16
Fujian	118.4	2.41	52.2	9.99
Jiangxi	264.5	2.52	39.7	5.31
Shandong	84.0	1.05	-8.2	0.71
Henan	144.5	1.76	49.8	3.21
Hubei	110.4	1.79	96.3	6.66
Hunan	231.4	2.66	64.1	3.20
Guangdong	80.4	0.93	93.1	7.43
Guangxi	263.1	3.44	189.2	7.99
Hainan	84.2	1.38	-3.5	1.09
Sichuan	544.3	9.25	193.7	15.47
Guizhou	138.4	1.55	184.2	6.35
Yunnan	385.5	7.08	224.1	15.37
Tibet	51.7	9.73	42.5	1.50
Shaanxi	46.2	1.13	77.1	5.99
Gansu	-4.7	0.24	42.6	2.47
Qinghai	11.4	0.30	6.6	0.39
Ningxia	0.2	0.04	6.0	0.15
Xinjiang	34.4	1.14	36.3	3.02

Table S4 C sink and areas of natural and planted forest stands in various provinces and regions from 1977 to 2018

Province	Natural forest stand		Planted forest stand	
	Area change	C sink	Area change	C sink
	10^4 ha	Tg C yr^{-1}	10^4 ha	Tg C yr^{-1}
China	1457.2	55.06	3601.4	32.99
Beijing	21.3	0.16	25.1	0.15
Tianjin	0.1	0.00	8.4	0.05
Hebei	75.0	0.66	97.9	0.87
Shanxi	58.1	0.71	85.3	0.55
Inner Mongolia	-77.7	6.50	219.6	1.77
Liaoning	44.8	1.40	71.6	1.03
Jilin	-58.0	2.53	79.3	1.10
Heilongjiang	-75.4	2.33	159.3	2.13
Shanghai	-0.2	-0.00	6.7	0.06
Jiangsu	2.2	0.03	102.5	0.78
Zhejiang	83.8	1.49	41.4	0.65
Anhui	18.1	0.68	95.2	1.09
Fujian	-12.9	1.97	183.4	2.49
Jiangxi	78.5	1.69	225.7	1.58
Shandong	-2.5	0.03	78.3	0.93
Henan	55.8	0.91	138.5	1.24
Hubei	153.1	2.38	53.7	0.72
Hunan	56.7	0.97	238.7	1.84
Guangdong	-96.2	0.69	269.7	1.99
Guangxi	62.9	1.75	389.3	2.93
Hainan	4.0	1.05	7.8	0.25
Sichuan	364.5	7.42	373.5	3.51
Guizhou	106.9	1.19	215.8	1.66
Yunnan	395.4	7.52	214.2	1.80
Tibet	88.7	7.47	5.6	0.03
Shaanxi	25.1	1.92	98.2	0.53
Gansu	-23.2	0.34	61.2	0.51
Qinghai	13.0	0.27	5.0	0.06
Ningxia	2.1	0.03	4.1	0.04
Xinjiang	43.8	0.97	27.0	0.67

Table S5 Area, C pool, C density and C sink of forest for each age group from 1977 to 2018

Group	Periods	Area 10^4 ha	C pool Tg C	C density Mg C ha^{-1}	C sink Tg C yr^{-1}
young-aged	1977–1981	4185	604	14.4	
	1984–1988	4949	831	16.8	32.5
	1989–1993	5185	854	16.5	4.6
	1994–1998	4771	835	17.5	-3.7
	1999–2003	4724	876	18.5	8.2
	2004–2018	5262	992	18.9	23.2
	2009–2013	5269	1047	19.9	11.0
	2014–2018	5654	1261	22.3	42.7
mid-aged	1977–1981	4342	1536	35.4	
	1984–1988	4073	1373	33.7	-23.3
	1989–1993	4542	1577	34.7	40.8
	1994–1998	4456	1622	36.4	8.9
	1999–2003	4964	1764	35.5	28.5
	2004–2018	5201	1927	37.1	32.6
	2009–2013	5312	2058	38.8	26.3
	2014–2018	5425	2327	42.9	53.8
old-aged	1977–1981	3823	2577	67.4	
	1984–1988	4148	2681	64.6	14.8
	1989–1993	4244	2972	70.0	58.2
	1994–1998	4014	2931	73.0	-8.1
	1999–2003	4591	3222	70.2	58.2
	2004–2018	5096	3508	68.8	57.2
	2009–2013	5799	3968	68.4	92.1
	2014–2018	6330	4387	69.3	83.8

Table S6 Classification of forest ages for different forest types in China[a] (modified from Xiao, 2005; Xu et al., 2010)

Forest type	Region[b]	Origin	Age groups (years)					Age-class period
			Young	Middle-age	Premature	Mature	Overmature	(years)
Cypress, Mixed conifer-broadleaf forest, *Picea*, *Pinus koraiensis*, *Tsuga chinensis*	North	Natural	≤60	61–100	101–120	121–160	≥161	20
	North	Planted	≤40	41–60	61–80	81–120	≥121	20
	South	Natural	≤40	41–60	61–80	81–120	≥121	20
	South	Planted	≤20	21–40	41–60	61–80	≥81	20
Abies, *Larix*, Mixed coniferous forest, *Pinus densifolia*, *Pinus sylvestris*, *Pinus thunbergii*	North	Natural	≤40	41–80	81–100	101–140	≥141	20
	North	Planted	≤20	21–30	31–40	41–60	≥61	10
	South	Natural	≤40	41–60	61–80	81–120	≥121	20
	South	Planted	≤20	21–30	31–40	41–60	≥61	10
Pinus armandi, *Pinus densata*, *Pinus kisiya*, *Pinus massoniana*, *Pinus tabulaeformis*, *Pinus taeda*, *Pinus yunnanensis*	North	Natural	≤30	31–50	51–60	61–80	≥81	10
	North	Planted	≤20	21–30	31–40	41–60	≥61	10
	South	Natural	≤20	21–30	31–40	41–60	≥61	10
	South	Planted	≤10	11–20	21–30	31–50	≥51	10
Casuarina, *Eucalyptus*, *Populus*, *Sassafras*, softwoods	North	Natural	≤10	11–15	16–20	21–30	≥31	5
	South	Planted	≤5	6–10	11–15	16–25	≥26	5
Acacia, *Acer*, *Betula*, *Davidia*, *Ulmus*	North	Natural	≤30	31–50	51–60	61–80	≥81	10
	North	Planted	≤20	21–30	31–40	41–60	≥61	10
	South	Natural	≤20	21–40	41–50	51–70	≥71	10
	South	Planted	≤10	11–20	21–30	31–50	≥51	10
Cinnamomum, *Fraxinus*, Hardwoods, *Juglans*, Mixed broadleaf forest, *Phellodendron*, *Phoebe*, *Quercus*, *Tillia*	North & South	Natural	≤40	41–60	61–80	81–120	≥121	20
	North & South	Planted	≤20	21–40	41–50	51–70	≥71	10
Cunninghamia lanceolate, *Cryptomeria fortunei*, *Keteleeria*, *Metasequoia glyptostroboides*, tropical forest	South	Planted	≤10	11–20	21–25	26–35	≥36	5

[a] Regulations for age-class and age-group division of main tree-species: The age-class period is the quantitative dimension of the age of the tree, that is, the tree age unit, which is the number of

years included in each age class. It is divided into five types namely 1-year, 2-year, 5-year, 10-years and 20-year. This is summed up by forest workers in long-term practice, and reflects the growth rate of forests. Age class is the classification of the average age of trees, that is, according to the requirements of forest management and the biological characteristics of tree species. It is divided into several classes according to a certain number of years (age-class period) as an interval. Age group refers to the group of the forest according to the harvest age or cutting-for-regeneration age, combined with the age-class period, reflecting the different stages of forest cultivation, protection and utilization. The age group is the integration of age class, and is usually divided into five age groups: young, middle-aged, premature, mature and overmature forest. One age group can contain 1 to 3 age classes.

The theoretical basis for the division of age class and age group in China is forest maturity theory. Forest maturity theory is one of the basic theories in forest management and the basis of forest adjustment and control. Its purpose is to study and solve the problem of maximizing the utilization of forest resources. Research on forest maturity theory confirms that forest maturity is the state in which the forest achieves the most suitable management purpose in the process of growth and development. Correspondingly, the forest maturity age represents the most suitable growth period for harvesting and utilization under certain economic and natural conditions. The implementation basis of age group division is the forest harvesting management policy, which determines that the most suitable age stage for harvesting and utilization is the forest maturity stage. At the same time, the initial age of the mature stage is stipulated as the harvest age, that is, the minimum harvest age of the forest stipulated by law. Therefore, the above-mentioned process from theory to practice is the theory of forest maturity, determining age-class period, determining maturity age, specifying harvest age, determining age class and age group, and finally applying it to management practice.

Simply put, China's forest inventory data focus on whether the wood can be harvested and each tree species is divided into 5 forest age groups according to whether it has reached the harvesting stage: young, middle-aged, premature, mature, and overmature forest.

[b] North China here includes the provinces of Liaoning, Jilin, Heilongjiang, Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Shandong, Henan, Shannxi, Gansu, Qinghai, Ningxia, and Xinjiang. South China includes the provinces of Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Tibet, and Yunnan.

Table S7 Estimates of biomass C pool, C density and C sink in China's forests

Period	Area	C pool	C density	C sink	Reference
	10^6 ha	Tg C	Mg C ha^{-1}	Tg C yr^{-1}	
1977–1981	116.5	4302.6	36.9	-	Fang et al., 2007
	116.6	4210	36.1	25	Zhang et al., 2013
	95.6	3700	38.7	-30	Li et al., 2015
	116.6	4097.3	38.2	-	Zhao et al., 2019
	1166	4128.5	35.4	-	Zhao et al., 2021
	95.6	3690	38.6	-20	Zhang et al., 2021
	123.5	4717	38.2	-	This study
1984–1988	124.2	4458.0	35.9	22.2	Fang et al., 2007
	124.5	4180	35.5	-4	Zhang et al., 2013
	102.2	3760	36.8	12	Li et al., 2015
	121.0	4126.8	36.0	5.9	Zhao et al., 2019
	124.5	4161.5	33.4	4.7	Zhao et al., 2021
	102.2	3710	36.3	3	Zhang et al., 2021
	131.7	4885	37.1	23.9	This study
1989–1993	131.8	4930.7	37.4	94.5	Fang et al., 2007
	132.2	4520	34.2	68	Zhang et al., 2013
	108.6	4110	37.9	70	Li et al., 2015
	128.6	4475.8	36.7	69.8	Zhao et al., 2019
	132.2	4510.5	34.1	69.8	Zhao et al., 2021
	108.6	4080	37.6	74	Zhang et al., 2021
	139.7	5402	38.7	103.5	This study
1994–1998	132.2	5011.6	37.9	16.2	Fang et al., 2007
	129.2	4500	34.8	-4	Zhang et al., 2013
	129.2	4660	36.0	108	Li et al., 2015
	129.2	4478.9	34.7	0.6	Zhao et al., 2019
	129.2	4478.9	34.7	-6.3	Zhao et al., 2021
	129.2	4560	35.3	96	Zhang et al., 2021
	132.4	5388	40.7	-2.9	This study
1999–2003	142.8	5851.9	41.0	168.1	Fang et al., 2007
	142.8	5410	37.9	182	Zhang et al., 2013
	142.8	5510	38.6	170	Li et al., 2015
	142.8	5375.0	37.6	179.2	Zhao et al., 2019
	142.8	5375.0	37.6	179.2	Zhao et al., 2021
	142.8	5430	38.0	174	Zhang et al., 2021
	142.8	5862	41.1	94.9	This study

2004–2008	155.6	6240	40.1	166	Zhang et al., 2013
	155.6	6090	39.1	116	Li et al., 2015
	155.6	6558.8	42.2	236.8	Zhao et al., 2019
	155.6	6629.8	42.6	251.0	Zhao et al., 2021
	155.6	6100	39.2	134	Zhang et al., 2021
	155.6	6427	41.3	112.9	This study
2009–2013	164.6	7267.5	44.5	141.7	Zhao et al., 2019
	164.6	7375.1	44.8	149.1	Zhao et al., 2021
	164.6	6810	41.4	142	Zhang et al., 2021
	163.5	7074	43.3	129.4	This study
2014–2018	179.9	7906	44.0	106.2	Zhao et al., 2021
	179.9	7970	44.3	232	Zhang et al., 2021
	174.1	7975	45.8	180.2	This study

Supplementary Figures

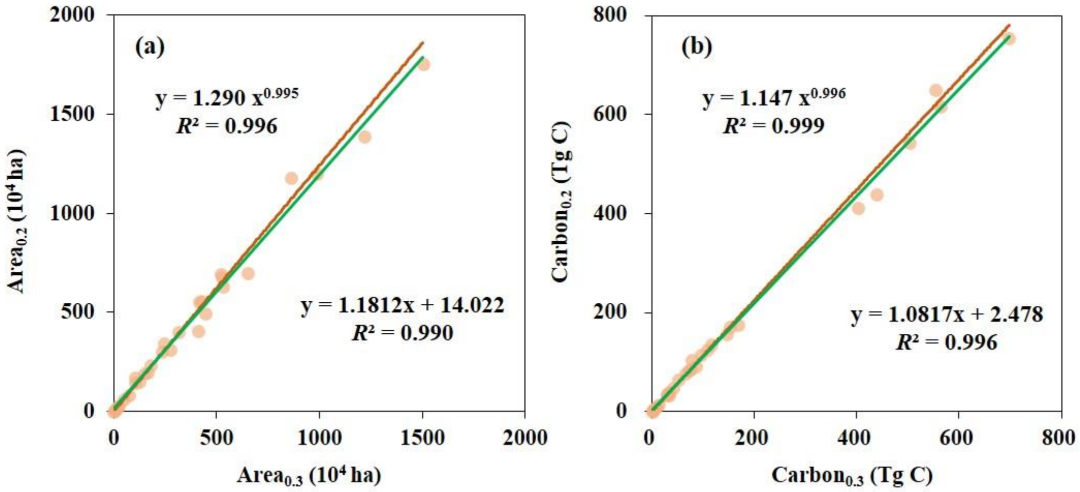

Figure S1 (a) power function transformations and linear relationship transformations for area; (b) power function transformations and linear relationship transformations for C pools.

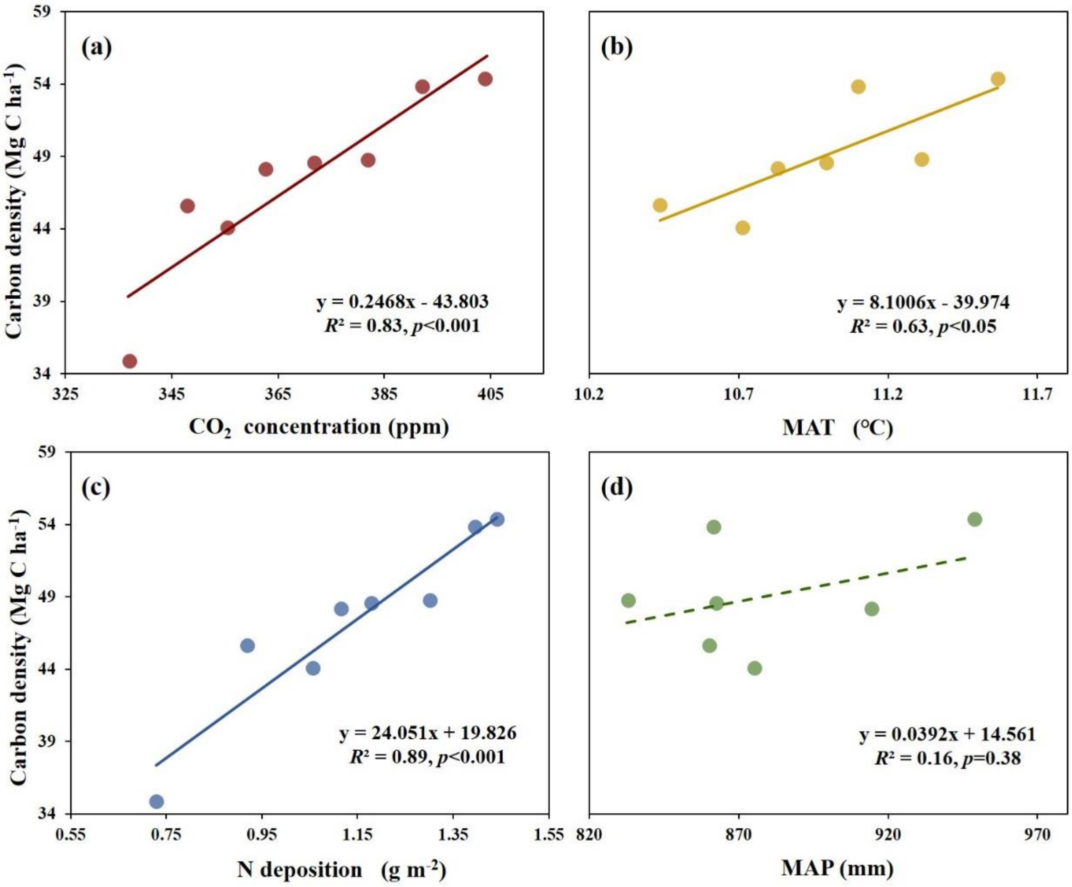

Figure S2 CO_2 concentration (a), MAT (b), total N deposition (c) and MAP (d) impact on the average forest biomass C density of different species and different age classes.

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