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Preliminary estimation of the organic carbon pool in China's wetlands

ZHENG YaoMin[1], NIU ZhenGuo[1*], GONG Peng[1,2,3*], DAI YongJiu[4] & SHANGGUAN Wei[4]

[1] *State Key Laboratory of Remote Sensing Science, Jointly Sponsored by Institute of Remote Sensing Applications, Chinese Academy Sciences and Beijing Normal University, Beijing 100101, China;*
[2] *Ministry of Education Key Laboratory for Earth System Modeling, Center for Earth System Science, Institute for Global Change Studies, Tsinghua University, Beijing 100084, China;*
[3] *Department of Environmental Science, Policy and Management, University of California, Berkeley, California 94720-3114, USA;*
[4] *College of Global Change and Earth System Science, Beijing Normal University, Beijing 100875, China*

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Accurate estimation of wetland carbon pools is a prerequisite for wetland resource conservation and implementation of carbon sink enhancement plans. The inventory approach is a realistic method for estimating the organic carbon pool in China's wetlands at the national scale. An updated data and inventory approach were used to estimate the amount of organic carbon stored in China's wetlands. Primary results are as follows: (1) the organic carbon pool of China's wetlands is between 5.39 and 7.25 Pg, accounting for 1.3%–3.5% of the global level; (2) the estimated values and percentages of the organic carbon contained in the soil, water and vegetation pools in China's wetlands are 5.04–6.19 Pg and 85.4%–93.5%, 0.22–0.56 Pg and 4.1%–7.7%, 0.13–0.50 Pg and 2.4%–6.9%, respectively. The soil organic carbon pool of China's wetlands is greater than our previous estimate of 3.67 Pg, but is lower than other previous estimates of 12.20 and 8–10 Pg. Based on the discussion and uncertainty analysis, some research areas worthy of future attention are presented.

wetland carbon pool, inventory approach, remote sensing, soil carbon density, wetland vegetation

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Wetlands have the highest terrestrial ecological value per unit area [1], the strongest carbon sequestration capability [2], and the greatest significance for biodiversity protection [3]. Therefore, wetlands have been described as the kidneys of the earth [4]. Protecting wetlands and promoting their carbon fixation potential, as well as reducing carbon emissions, have attracted significant attention from the international community (http://www.wetlands.org, 2010). Accurate estimation of the size of wetland carbon pools is a pre-requisite for protection of wetland resources and implementation of carbon sink enhancement plans, and its importance and urgency have been gradually recognized by scientists and politicians. However, experimental study on estimation of wetland carbon pools is just in the initial stages, and there are still many problems to be solved [5]. Since soil is a major component of wetland ecosystems for carbon sequestration, estimates of carbon pools in the soils of China are essential for accurately appraising global terrestrial carbon inventories and are critical for optimizing strategies to mitigate the accumulation of CO_2 in the atmosphere. Most of the shared data on soil carbon in China at the national scale are estimates of soil organic carbon based on the different sets of the database of China's second national soil survey in the 1980s. The estimates of soil organic carbon in China's wetlands and the contribution of wetland organic carbon to global levels have not been well documented.

Studies of wetlands indicate that the main challenges of wetland carbon pool measurement include three aspects: the

*Corresponding authors (email: zhgniu@irsa.ac.cn; gong@irsa.ac.cn)

complexity of the wetland carbon cycle [6,7], the difficulty of defining wetland boundaries [8] and the lack of monitoring data [3,9]. Study of the processes of the wetland carbon cycle is restrained by several factors, such as climate, topography, hydrology, soil, vegetation and human interference, and by the great variation in the rate of decomposition and transformation products that have resulted in substantial complexities of spatial heterogeneity of wetland carbon distribution. Climate, topography and hydrological conditions are the dominant driving factors of wetland carbon cycle processes, and determine significant variables in wetlands, including changes of water level, NPP, chemical activity, organic matter, and the amount of deposition and output [10].

The soil carbon pool is an important part of the wetland carbon pools. It is mainly affected by three factors: the influence of factors such as hydrology, temperature, pH and Eh on the decomposition microenvironment, the nature of the decomposition substrate, and its decomposition time. Vegetation affects the wetland carbon cycle by stomatal regulation and the capacity of carbon fixation mainly depends on vegetation types, concentrations of CO_2 in the vegetation canopy, and seasonal changes in humidity and water level. Vegetation residues are often converted into peat, because of the constraints of water-rice and strong reducing conditions [11]. The ability of CO_2 to be taken up by water is mainly influenced by the climate, N, P, Fe [12], water acidification, eutrophication, enhanced solar ultraviolet radiation, and the adjacent ecological system. The carbon output of water bodies mainly includes runoff output, mineralization and fishing [13]. However, the regional patterns and causes of wetland carbon sources and sinks remain uncertain. Human interference may cause changes in the carbon pattern, such as an increase in greenhouse gas emissions. In the last few centuries, the carbon from peatland emitted into the atmosphere has reached 160–250 Tg/a because of drainage or cultivation [14]. This is roughly equivalent to 1.8%–2.8% of the 9 Pg [15], which is estimated to be the carbon emissions caused by human fossil fuel burning in 2010. Generally, the complexity of the wetland carbon cycle causes difficulty in estimating the wetland carbon pool.

A premise of wetland carbon pool measurement and wetland area statistics is the determination of wetland boundaries. However, the scientific definition and boundary problem of wetlands are two difficult scientific issues that remain to be solved by global scientists. Although the unique characteristics of hydrology, soil and vegetation of wetlands have been recognized [16], these characteristics change gradually, and so the boundary of wetlands, which is a continuum composed of land and water, is difficult to clearly define. The boundaries show seasonal characteristics and inter-annual variability due to their adopting some features of wetland or using different times of observational data and methods [8]. The estimates of wetland organic carbon pools not only involve the inter-conversion of ecosystem types such as woodland, farmland, grassland, wetland, place of residence and other land, but also relate to changes in the carbon sources or sinks of living biomass, dead organic matter, mineral soil, organic soil and water bodies. All countries will encounter to varying degrees problems from a lack of data [6]. Wetland monitoring has just begun in China [9], and the inadequacy of carbon monitoring will continue to bring about difficulties in estimating the organic carbon in China's wetlands.

On a global scale, previous studies of the global carbon cycle show that the global wetland carbon pool size is estimated to be 154–550 Pg (Table 1). These previous studies used a small number of soil profiles or some limited documents. In China, Ma et al. [34], Sun et al. [35], Liu and Lü [36] have engaged in some studies of organic carbon of peat soils, swamp soils and marsh vegetation in Northeast China, but the results are of different magnitudes. Ma et al. found that there was 270 Tg of organic carbon accumulated in the mire soils and peatlands of Sanjiang Plain, while Sun et al. found that there was only 12.05 Tg of organic carbon accumulated in the three Northeastern provinces of China. Wang et al. [37], Pan et al. [38], Xie et al. [39] and Liu et al. [40] reported 0.90–5.09 Pg of organic carbon in paddy soils in China. In recent years, Yu et al. [41] and Shi et al. [42,43], Zhang et al. [44] and Niu et al. [5] have evaluated carbon pools of wetland soils in China, with results ranging

Table 1 Carbon pools in global wetlands

Type	Carbon pool (Pg)	Area ($\times10^4$ km^2)	Reference
Global wetland soil b)	550	–	a)
	225–377	530–570	[17]
Global wetland b)	280	280	[18]
	300	500	[19]
	377	–	[20]
	225	350	[21]
	357	1745	[22]
	202	280	[23]
	154	240	[24]
Global peatland b)	330	240	[25]
	455	269	[26]
	500±100	–	[27]
Global peatland c)	45	120	[28]
Global peatland d)	120–260	–	[29]
	160–165	–	[30]
	450	–	[31]
	243–253	400	[32]
Global wetland vegetation e)	0.5×10^2–13.5×10^2	–	[33]

a) http://www.wetlands.org/articlemenu.aspx?id=ae774022-0c1a-4293-a107-a73225128e75; b) 1 m; c) 0.33 m; d) unspecified; e) t C/km^2.

from 3.67 to 12.20 Pg. How much organic carbon will remain in China's wetlands? The objectives of this study are (1) to estimate the organic carbon pools as soil organic carbon, vegetation carbon and organic carbon in water bodies of wetlands in China using an inventory approach, and (2) to calculate their ratios at the global scale and at the national level, respectively.

1 Materials and methods

1.1 Data sources and preparation

The Chinese wetland remote sensing map has been renewed with field verification and accuracy evaluation by using the TM images (2007–2009). More than 10000 photos were collected to validate the 2008 wetland map [45].

The 1∶1000000 soil map of China was compiled by the Institute of Soil Science, Chinese Academy of Sciences based on the results of the Second National Soil Survey of China [42]. This map is the most detailed soil map in China at the national scale. It is classified using the Genetic Soil Classification of China (GSCC), which includes 12 orders, 61 great groups, 235 sub-great groups, and 909 families. There are 94303 map polygons in the map, including 85257 soil map polygons and 9046 non-soil map polygons. More than half of the soil map polygons are at the sub-great group level, and the others are at the great group or family level. The latitude and longitude of the centers of the map polygons were extracted from the coverage file using GIS tools.

Simultaneously, soil survey data was further supplemented by 7799 soil profiles (33011 as the total soil samplings) from local soil survey data [46].

1.2 Research methods and data processing

The improved inventory approach was used to calculate the organic carbon storage of wetland mainly including soil, vegetation and water bodies based on previous study [5].

The organic carbon densities of wetland soils of various depths were determined by multiplying the content of organic carbon by soil bulk density. In order to facilitate international exchange, the soil depth considered is 1 m.

The soil organic carbon density of a specific pedogenic layer (D_j, g/cm^2) and the total soil organic carbon storage in China's wetland(C, g) were calculated from soil organic matter concentrations (O_{ij}, %) and bulk density values (W_j, g/cm^3) as follows:

$$C = \sum S_j D_j, \quad (1)$$

$$D_j = \sum 0.58 W_j H_{ij} O_{ij}, \quad (2)$$

where i is the number of the pedogenic horizon, j is the number of soil types, and S_j is the wetland soil area (cm^2), 0.58 is the Bemmelen index that converts organic matter concentration to organic carbon content, and H_{ij} is soil thickness (cm). 1 Pg=1×10^{15} g=10×10^6 t.

Soil bulk density was determined by the core method and was collected from reports and documents. The distribution of China's wetland soils is taken from a spatial overlay of China's wetland remote sensing map and the "1∶1000000 China soil map", excluding non soil topographic objects such as farms, salt pans, salt encrustations, rivers, lakes, reservoirs, shells, rocks and urban areas. There are 53 soil types mainly including marsh soil, peat soil, meadow soil and other soils in China's wetland area (Table 2). For the organic carbon density of China's wetland and its soil area refer to Table 2 and Figure 1.

2 Results and discussion

2.1 Estimates of the wetland organic carbon pool in China

Recent studies of soil organic carbon in China's wetlands suggest that the research areas are mainly concentrated in the Northeast Plain, and the plain of the lower reaches of the Yangtze River, Coast and Qinghai-Tibetan Plateau. However, these results cannot be safely used for the correction of wetland soil carbon density at the national scale, because of great differences in sampling depth, sampling time, research perspective and study methods, as well as soil nomenclature, etc. Zhao et al. [47] found that the soil organic carbon density in Zhalong marsh was 3.79 g/cm^2 in 2006, which is the same as the result given by Zhang et al. [44]. The Zhalong result, which was the same as that from the Sanjiang Plain, was lower than that from the Zoige wetland, and higher than that from other wetlands in China, but significantly lower than the global level. Xi et al. [48] found that the soil carbon density in the Northeast Plain was in proportion to the national average, and that the organic carbon density of a marsh soil in Heilongjiang was 3.28 g/cm^2. The result for the topsoil (20 cm) showed a total increase of 9.2% in the last 20 years. The results were very close to that of Zhao et al. [47]. According to the results of Xi et al. [48], Zhao et al. [47] and Liu [49], the organic carbon density of marsh soils and peat soils in China were revised to 3.54 and 4.47 g/cm^2, respectively. These studies suggest that the organic carbon storage and organic carbon density in soils of China's wetland vary with and are modulated by different soil types (Table 2). The arithmetic mean and the weighted mean were used to calculate the carbon pool in this paper, which shows that the soil organic carbon pool in China's wetlands ranges from 5.04 to 6.19 Pg.

The carbon density of wetland vegetation in China is shown in Table 3. The distribution data of wetland vegetation is from the literature. The areas of *Larix gmelinii*, *Larix olgensis Henry*, mangrove, *Phragmites australis* and *Scirpus mariqueter* are 10.59×10^4 km^2 [59], 7×10^3 km^2 [60], 230.82 km^2 [61], 4×10^3 km^2 [62] and 42.35 km^2 [63],

Table 2 Organic carbon density of wetland soils in China

Soil type	FAO/UNESCO	ID	Number of profiles	Bulk (g/cm^3)	Carbon density (g/cm^2)	Area of soil (km^2)	Organic carbon pool (Tg)
Brown coniferous forest soils	–	10000	32	1.33	2.29	783.12	17.93
Dry red soils	–	13000	22	1.29	1.09	280.27	3.05
Cinnamon soils	Eutric cambisols	14000	752	1.37	1.76	2034.27	35.80
Grey cinnamon soils	Haplic/calcic luvisols	15000	146	1.36	3.60	451.82	16.27
Black soils	Haplic phaeozems	16000	3	1.31	3.56	1605.22	57.15
Grey forest soils	–	17000	20	1.33	3.26	159.60	5.20
Chernozems	Chernozems	18000	145	1.32	2.93	3914.95	114.71
Chestnut soils	Kastanozems	19000	215	1.37	1.68	6148.72	103.30
Castano cinnamon soils	Kastanozems	20000	79	1.40	1.20	230.24	2.76
Dark loessial soils	Anthrosols	21000	55	1.38	1.88	20.70	0.39
Brown calcic soils	Cambisols	22000	41	1.38	0.97	2896.59	28.10
Sierozems	Haplic Sierozems	23000	90	1.41	1.00	182.09	1.82
Grey desert soils	Haplic calcisols	24000	33	1.39	1.66	436.14	7.24
Grey-brown desert soils	Haplic calcisols	25000	22	1.41	0.58	860.15	4.99
Brown desert soils	Solonchaks	26000	32	1.36	0.59	1157.04	6.83
Loessial soils	Calcaric regosols	27000	62	1.38	0.82	417.40	3.42
Red clay	–	28000	54	1.34	0.78	38.22	0.30
Alluvial soils	Alluvial soils	29000	307	1.58	1.27	5377.14	68.29
Takyr	–	30000	4	1.32	0.24	3.93	0.01
Blown sand soils	Blown sand soils	31000	142	1.62	0.51	6924.93	35.32
Limestone soils	Limestone soils	32000	106	1.23	1.94	1228.34	23.83
Andosol	–	33000	21	1.40	2.83	213.06	6.03
Purple soils	–	34000	207	1.40	1.02	2370.73	24.18
Skeleton soils	–	37000	169	1.41	0.94	1281.90	12.05
Meadow soils	Umbric gleysols	38000	130	1.31	3.05	51134.74	1559.61
Lime concretion black soils	–	39000	69	1.32	1.18	383.95	4.53
Mountain meadow soils	–	40000	58	1.40	6.54	4.99	0.33
Shrubby meadow soils	–	41000	3	1.39	1.03	1254.24	12.92
Chao soils	Chao soils	42000	914	1.42	6.92	12063.00	834.76
Marshy soils	–	43000	127	1.28	3.54[c)]	30239.18	1070.47
Peat soils	–	44000	25	1.38	4.47[d)]	1150.09	51.41
Saline soils	–	45000	105	1.38	0.97	10861.88	105.36
Coastal saline soils	–	47000	58	1.39	1.42	5754.23	81.71
Acid sulphate soils	–	48000	8	1.32	2.66	93.89	2.50
Frigid plateau solonchaks	–	49000	19	1.35	0.57	2822.69	16.09
Solonetz	Solonetz	50000	22	1.29	0.89	1414.21	12.59
Paddy soils	Fluvisols/luvisols	51000	1201	1.36	1.30	15094.19	196.22
Cumulated soils	Cumulated soils	52000	112	1.47	1.34	623.15	8.35
Irrigation desert soils	–	53000	6	1.39	3.15	211.08	6.65
Alpine meadow soils	–	54000	17	1.39	8.89	7509.99	667.64
Subalpine meadow soils	–	55000	8	1.35	10.10	3031.95	306.23
Alpine steppe soils	–	56000	99	1.51	1.35	17615.82	237.81
Subalpine steppe soils	–	57000	234	1.37	1.82	2718.70	49.48
Shrubby steppe soils	–	58000	381	1.43	1.65	398.40	6.57
Latosols	Haplic acrisols	81000	63	1.29	1.67	1016.21	16.97
Latored soils	Haplic acrisols/alisols	82000	121	1.28	1.46	2680.76	39.14
Red soils	Luvisols	83000	333	1.32	1.59	6047.86	96.16
Yellow soils	Haplic alisols	84000	181	1.39	2.63	1056.32	27.78
Yellow brown soils	Ferric/haplic luvisols	85000	169	1.37	2.80	1090.08	30.52
Yellow cinnamon soils	–	86000	64	1.30	0.89	1630.13	14.51
Brown soils	Haplic/albic luvisols	87000	320	1.35	2.26	1694.59	38.30
Dark brown soils	Haplic luvisols	88000	170	1.39	1.34	4540.63	60.84
Albisols	Eutric planosols	89000	7	1.33	2.85	1789.15	50.99
Summation	–	–	7799	1.37	2.24[a)]–2.75[b)]	224942.65	5038.72–6185.92

a) The arithmetic mean; b) the weighted mean; c) and d) the amended value.

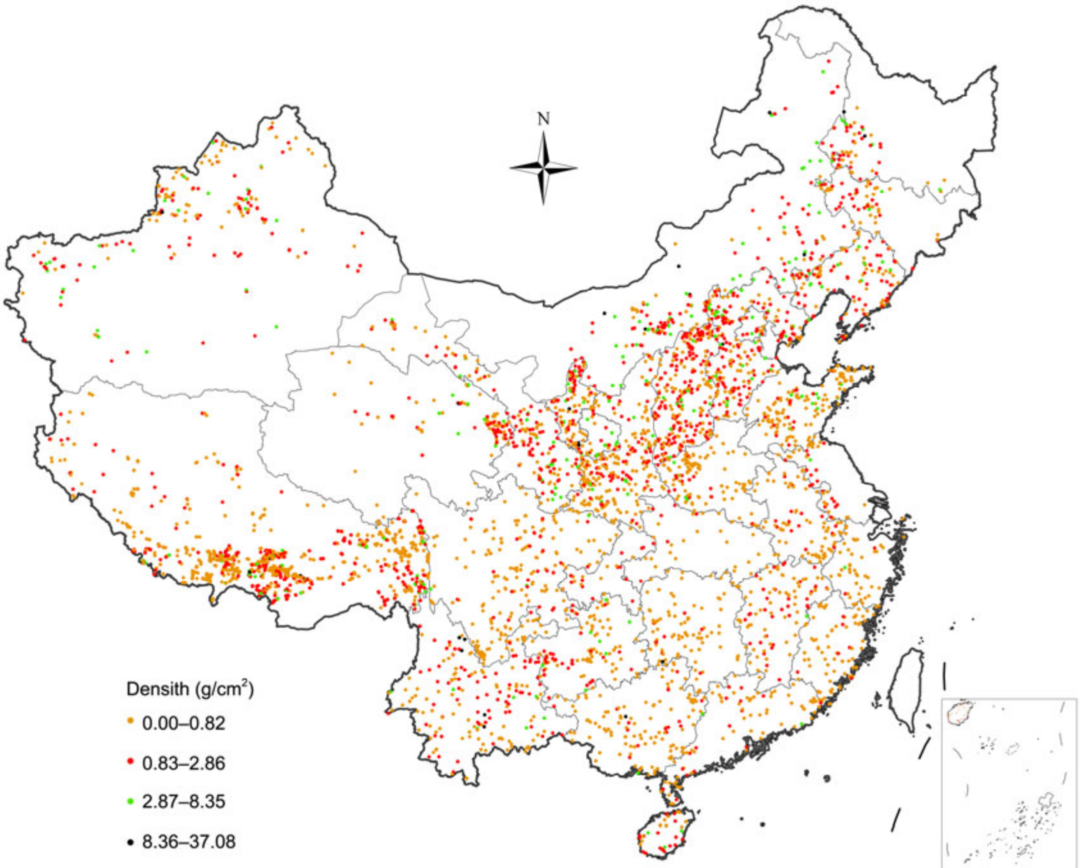

Figure 1 Chinese wetland soil organic carbon density based on the second national soil survey data.

respectively. The carbon pools of other vegetation types for which data are lacking are estimated using the conversion formula in reference [64].

The total organic carbon in water bodies of China is estimated from the Refferences [65,66]. For many years the average amount of water resources reaches 2.81×10^{12} m^3, and the average carbon density in China's lakes is from 0.64×10^4 to 1.65×10^4 μmol/L.

Primary results are as follows: (1) the organic carbon pool of China's wetlands is between 5.39 and 7.25 Pg, accounting for 1.3%–3.5% of the global level. (2) The estimated values and percentages of the organic carbon contained in the soil, water bodies and vegetation pools in China's wetlands are 5.04–6.19 Pg and 85.4%–93.5%, 0.22–0.56 Pg and 4.1%–7.7%, 0.13–0.50 Pg and 2.4%–6.9%, respectively.

2.2 The comparative analysis of wetland soil organic carbon pools in China

Estimates of China's terrestrial soil organic carbon storage vary greatly, and the estimations of wetland soil organic carbon storage have not been widely recognized. Based on the "1∶10000000 China soil map" and 725 soil profiles, Fang et al. [67] observed that the area of China's soils was 944.86×10^4 km^2, the average soil carbon density was 2.03 g/cm^2, and the total carbon storage was 185.69 Pg. Pan et al. [68] found that China's pools of soil organic carbon and inorganic carbon were 50 and 60 Pg respectively, according to 2500 soil profiles [69]. Based on the "1∶4000000 China soil map"[70], Wang et al. [37,71] reported that the organic carbon pool of terrestrial soil in China was 100.18 and 92.42 Pg, according to the two national soil survey data sets from 236 and 2473 soil profiles respectively. Modeling methods were used to calculated soil carbon storage in China by Li et al. [72] and Wu et al. [73], and the results were 82.65 and 70.30 Pg, respectively. Based on data from the second national soil survey and 810 soil profiles from Northwest China especially from the Qinghai-Tibetan Plateau, Yang et al. [74] used the relationships among organic carbon density, bulk density and depth change of soil profiles to estimate that the soil organic carbon pool in China was 69.10 Pg, while Li et al. [75] found that the total soil organic carbon pool in China was 88.3 Pg by using 2456 soil profiles. China's soil information system database, which was developed with the change from the genetic soil classification of China to the USA soil classification system, has been used to connect the organic carbon data of soil types in total polygons to the "1∶1000000 China soil map". Yu et al. [41,76] used the data to suggest that the total soil

Table 3 Organic carbon density of wetland vegetation in China

Community	Organic carbon density (t C/km^2)	Research area	Reference
Bruguiera gymnorrhiza	5.29×10^4	Beibu Gulf	[50]
Vicennia mariana	2.91×10^4		
Kandelia candel	1.92×10^4		
Rhizophora stylosa	1.28×10^4		
Aegiceras corniculatum	3.53×10^3		
Larix-Mosses	6.72×10^3	Xiao Hinggan Mountains	[51]
Larix-Carex	5.87×10^3		
Betula platyphylla Suk	3.23×10^3		
Alnus sibirica	2.87×10^3		
Larix-Herba	1.85×10^3		
Phragmites australis	4.02×10^3	Chongming	[52]
	2.90×10^3	Nansi Lake	[53]
		Baiyangdian Lake	[54]
	4.21×10^3	Liaoriver Estuary	[55]
	1.29×10^4	Yancheng	[56]
Submergedplants	2.25×10^3	Nansi Lake	[53]
Nelumbo nucifera	2.48×10^2		
Carex lasiocarpa	2.90×10^3	Sanjiang Plain	[34]
Glyceria acutiflora	4.97×10^2		
Carex pseudo-curaica	2.33×10^2		
Carex meyeriana Kunth	2.67×10^3	Zoige	[57]
Carex muliensis	2.65×10^3		
Artemisia tainingensis	2.40×10^3		
Imperata cylindrica+ Phragmites australis	3.49×10^3	Yancheng	[56]
Spartina alterniflora+ Herba Suaedae	2.60×10^3		
Spartina alterniflora	2.10×10^3		
Scirpus triqueter	1.33×10^3		
Herba Suaedae	5.04×10^2		
Scirpus mariqueter	5.1×10^2	Chongming	[58]

organic carbon pool in China was 89.14 Pg [41–43,76]. At the 236th Xiangshan Meeting, soil scientists argued that China soil organic carbon pool should be between 70 and 90 Pg, and 90 Pg was put forward as a default value [77]. There was some convergence between the domestic experts and scholars in terms of the total soil organic carbon pool in China, but there was still great uncertainty [78].

The organic carbon pool of wetland soils is an important part of the terrestrial soil organic carbon pools in China. There is great uncertainty about the carbon sequestrated in wetland soils in China. The results of Yu et al. [41] and Niu et al. [5] provided results which were different by 3–4 times. Based on the MODIS classification with a spatial resolution of 500 m [79], Yu et al. [41,76] noted that the area of wetland soil in China was 727900 km^2 and its carbon pool was 12.20 Pg. The organic carbon density of wetland soils in China was available from some data including organic carbon depth distribution and from some limited references, and the first national wetland resources census data (2000–2003) was added to evaluate wetland soil organic carbon pool in China, giving a result of 8–10 Pg [44]. Based on the studies of Yu et al. and Shi et al., Niu et al. used the ETM$^+$ data instead of MODIS data [79], and calculated that the total organic carbon pool of wetland soils in China was 3.67 Pg [5].

In order to meet the needs of research on climate change, Shangguan et al. [46] has established a distribution database of soil particle size in China, and has collected 8979 soil profiles, including 33039 layers which not only were from the second national soil survey data [80] and the “1∶1000000 soil distribution map”, but also were from local soil survey data, especially in Tibet, including soil bulk density data. Based on the studies of Niu et al. and Shangguan et al., the soil profiles, soil area data and the method of carbon density measurement have been supplemented and improved in this paper. The “1∶100000–250000 China wetland remote sensing map” was updated to 2008 as the base year which contained 1442 pieces of CBERS (01/02B) images as a data source, and the accuracy reached 98% after artificial interpretation and field verification [45]. The soil organic carbon density measurement was carried out through the method of classification and layering.

Compared to our previous study results of 3.67 Pg, this paper shows a higher result of 5.04–6.19 Pg, which is lower than the results of Yu et al. [41] and Zhang et al. [44], which were 12.20 and 8–10 Pg, respectively. The area of wetland soils in China decreased to 224942.65 km^2 (2008) from 244669 km^2 (2000), which shows that the increase in the organic carbon pool of wetland soils in China mainly depends on the increase of organic carbon density. This conclusion coincides with the perspectives of Zhao et al. [47] and Xi et al. [48]. This study reveals that the organic carbon pool of wetland soils in China has comparatively certainly risen, and the estimates of that are essential for better understanding the contributions of overall terrestrial carbon pools in China to the global carbon cycles.

This paper suggests that the organic carbon density of wetland soils in China varies from 0.24 to 10.10 g/cm^2, while the arithmetic mean and the weighted mean are 2.24 and 2.75 g/cm^2, respectively. Yu et al. [41] reported that the organic carbon density of wetland soils in China was 1.68 g/cm^2, and the results of Zhang et al. [44] ranged greatly from 0.75 to 8.76 g/cm^2. On the global scale, Mitra et al. [17] reported that the values of topsoil of 1 and 0.3 m depth were 6.00–15.00 g/cm^2 and 3.75 g/cm^2, respectively.

3 Uncertainty issues

The uncertainty of estimates of organic carbon storage of wetland in China is largely due to restrictions in research capacity and monitored data.

Firstly, there is the controversial issue of whether wetlands are carbon sinks or sources. This paper has not calculated the quantity and rates of carbon inflows and outflows, and has not attempted to separate out the relationships between carbon sources and sinks of wetlands in China. Thus this uncertainty remains.

Secondly, the organic carbon pool of wetlands, which includes soil, vegetation and water bodies, has been explored in this paper. Other types of organic carbon (animals, microorganisms, and sediments) and inorganic carbon are not included in the evaluation, since the conversion mechanisms between inorganic and organic carbon are still not clear because of the limits in research capacity and monitored data.

Thirdly, the estimates of organic carbon pools of wetlands (including soils, vegetations and water bodies) are affected by data sources, sample size and other factors, and there are some uncertainties.

(1) The representativeness of wetland soil profiles from the Second National Soil Survey of China is insufficient, and it causes a considerable bias in the results. The survey was not based on a special design for wetland soils, and the samples were too near to farmland. In addition, the density of samples was too low, being less than 8.12 per 10^4 km^2. Thus the effects of spatial heterogeneity of wetland soils were ignored. Also, wetlands have been subject to different levels of human disturbance in the past 30 years [3,45].

(2) The estimates of organic carbon pools in the vegetation and water bodies in wetlands of China were presented by using limited local data from some literature and books because of the lack of accurate monitoring data at the national scale.

Popular methods for estimating vegetation carbon storage of wetlands are an inventory approach and harvesting approach, and the underground biomass is evaluated by the root to top ratio. The carbon storage equals carbon density times area, and carbon density equals the biomass times a coefficient of carbon conversion. Although China's vegetation types and their distribution characteristics have been systematically summarized [81–85], there are no accurate data of the distribution area, except for a few communities such as *P. australis* and *Oryza sativa*. Although we have accessed many references describing the distribution area of China's wetland vegetation, there were only five types of wetland vegetation having data on their area of distribution. Many types of wetland vegetation, such as *Zostera marina Linn.L*, *Betula fruticosa*, *Kalidium foliatum* and *Glyptostrobus pensilis*, lack such data. In addition, in recent years the Chinese government has been working on vegetation restoration and planting in wetlands, and the results of this work are rarely documented. Moreover, this artificially planted vegetation in wetlands has a large potential for carbon sequestration.

We offer a preliminary evaluation of the organic carbon pool in water bodies in China by using limited data [65,66], since accurate monitoring data is lacking at the national level. The organic carbon density of two plateau lakes in Inner Mongolia replaced that of China's water bodies [66], and the average annual water resources volume took the place of the volume of China's water bodies [65]. However, the organic carbon density of water bodies in different basins of China varies greatly, and there exist the phenomena of inter-annual change and seasonal variation, which is affected by many factors. The representativeness of the data is therefore low. Moreover, the statistical data of water resources volume in China is dated, being based on material from 1956 to 1979 [65].

Fourthly, although the inventory approach was categorized in soil subtypes and layers to a depth of 1 m, there have been imperfections in the approach. It can only record the intermittent carbon storage, and it also ignores the influence of inter-annual and seasonal variation as well as the effects of soil microorganisms on organic carbon decomposition. There are not uniform standards for plot density, plot number and estimation methods. The level of detail and the spatial and temporal scales are different. Consequently the reliability and comparability of studies are poor. Nevertheless, the inventory approach for estimating organic carbon pools of wetlands in China is still a practical approach.

4 Prospect

(1) The mechanism of greenhouse gas emissions and carbon uptake is one focus of studies on wetland science. The effects of the key factors on the mechanism of carbon sources and sinks in different wetlands and elements should be attracting more research attention. These key factors include water level, temperature, pH, Eh, N, P, Fe, water acidification, eutrophication, human interference and other factors. The thresholds for transformation of carbon patterns and the response to global change are the key to studies on the carbon pools of wetlands.

(2) Research on carbon sequestration potential and technical measurement is an important part of international carbon cycle research. The scientific mode of wetland conservation and management, which is a goal of carbon emission and accumulation, should be actively explored. The active role of artificial wetland technology in the degradation of water carbon pollution, increasing soil and vegetation carbon accumulation should be fully investigated. Wetland vegetation surveys in China should be strengthened. The effects of various vegetation types on wetland carbon sequestration and the corresponding plan should be actively explored.

(3) Studies on the methods of carbon emission and sequestration should be strengthened, especially for different types of wetland by taking full advantage of rapid, large-scale, and real-time remote sensing in estimation methods. The monitoring network of different wetland types should

be gradually improved, as well as the construction of facilities such as flux towers, wireless sensors and remote transmission. The vegetation and moisture index, water depth and other wetland parameters should be measured, and a regularly updated database of high-resolution wetland distribution should be established by using the technology of RS and GIS. The inventory approach, remote sensing driving model and ecosystem process models should be coupled with the measured data of carbon flux, biomass, GPP or NPP in different wetlands and elements for carbon measurement and cross validation.

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