Carbon Stock and Carbon Cycle of Wetland Ecosystem

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Abstract Wetland ecosystem is an essential ecosystem in the world. Its organic carbon stock and carbon cycle are important basis of global carbon cycle researches and also major contents of global climate change researches. Researches have shown that wetland protection and restoration can promote carbon accumulation and reduce emission of greenhouse gases. This paper discussed influence of carbon stock and carbon balance of wetland ecosystem and emission of greenhouse gases, as well as the relationship between wetland and global climate changes. Finally, it made prospect on researches about carbon cycle of Dongting Lake.

Key words Wetland, Greenhouse gases, Carbon stock, Carbon balance, Dongting Lake

1 Introduction

A wetland is a land area that is saturated with water, either permanently or seasonally, such that it takes on the characteristics of a distinct ecosystem. It is an ecosystem with hydrological soil, vegetation, and biological characteristics distinct from land or water body, has the highest productivity in the world[1], and is listed as top three ecosystems together with forest and ocean[2]. Wetland plays an important role in global carbon cycle and is deemed as an essential carbon sink of greenhouse gases like CO_2 all the time[3]. This is mainly because incomplete decomposition of organic matters in wetland leads to accumulation of organic carbon, and forms huge carbon pool. However, due to human activities, natural wetlands are disturbed and reduced, and decomposition of organic carbon accelerates, leading to increase in emission of greenhouse gases. Therefore, enhancing the study on carbon storage and carbon cycle is of great significance to fixing carbon of wetland and reducing emission of greenhouse gases. There are a lot of researches about carbon stock and carbon cycle of wetland[4-11]. In the past, comparative researches about carbon stock of wetland are mainly concentrated on different vegetation communities and different land use types, while no integrated research is made on carbon stock of wetland vegetation, soil and water body. In this situation, we discussed changes in vegetation, soil and water body carbon stock of wetland, and analyzed factors influencing carbon stock of wetland, with the hope of providing scientific basis and reference for estimating carbon stock of wetland and researching carbon cycle.

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2 Carbon stock of wetland ecosystem

Wetland accounts for only 4% - 6% of total land area[4], but wetland ecosystem stores 20% - 30% of global carbon, up to 7.70 × 1010 tons, accounting for 35% of carbon element of terrestrial biosphere, so the wetland is the largest carbon pool[6]. Carbon storage of wetland is an essential part of global carbon cycle. Estimating carbon stock of wetland can accurately grasp functions of wetland in global climate changes.

2.1 Carbon stock of wetland vegetation Carbon pool of wetland vegetation includes aboveground and underground biomass and litter biomass. The aboveground biomass is generally estimated by sample plot measurement. Namely, firstly select certain area of sample plot, make estimation of biomass of arbor, shrub, and grass, and finally calculate total biomass of aboveground plants in unit area[7]. Underground biomass of wetland is measured mainly by earth core drilling method[12]. Litter includes all non-livable biomass[13] measured by entire sample harvesting method.

Vegetation of wetland ecosystem has high productivity, average net primary productivity is about 9 t/(hm^2 · a), the maximum value is up to 20 t/(hm^2 · a). The study of Mei Xueying *et al.*[8], indicates that existing biomass of reeds is as high as 60.0 to 130.0 t/hm^2 (91.0 t/hm^2 on average) and carbon stock of vegetation is 26.6 to 57.4 t/hm^2 (40.2 t/hm^2 on average). Wu Qin *et al.*[9] studied wetland in Poyang Lake and found that Carex biomass is up to 45 t. hm -2 and the reed biomass is 40 t/hm^2. Kang Wenxing *et al.*[10] studied wetland in Dongting Lake and found that carbon density of arborescent stratum is 15.61 to 40.50 t/hm^2, herbaceous stratum is 5.91 to 21.63 t/hm^2, hydrophyte is 1.46 to 3.49 t/hm^2 (14.95 t/hm^2 on average), higher than that in temperate zone. Wetland vegetation is mainly herbaceous plant which has high replacement amount every year and has strong carbon fixation ability. The study of Mei Xueying *et al.*[8] indicates that the carbon fixation capacity of reed wetland at entrance of Changjiang River is 11.1 to 24.1 t/(hm^2 · a), which is 2.3 to 4.9 times the average carbon fixation capacity of national land coverage, equivalent to that of forest ecosystem with the equal vegetation coverage, while the Scirpus mariqueter has the carbon fixation capacity of (6.3 ±2.8) t/(hm^2 · a)[11].

2.2 Carbon stock of wetland soil Saturated with water for a long time, wetland has low decomposition rate of plant with high productivity. Therefore, organic carbon stored in wetland soil is high. The carbon stock of wetland soil depends on the balance between input and output of organic carbon. Its input mainly comes from residual body of wetland animals and plants, while its output mainly includes decomposition of soil microorganisms, namely, the mineralization of organic matters. Factors influencing organic carbon of soil mainly include vegetation, climate, soil properties, and other factors. Wet and dry alternation of wetland may produce feedback to decomposition of organic carbon of soil. Different types of wetlands have different carbon accumulation or decomposition rate, and there is great difference in carbon density. Therefore, estimation of carbon stock of global wetland soil must be based on accurately grasping wetland type, area, and dynamic changes. The carbon pool of soil is calculated on the basis of organic carbon content and volume – weight of certain quantity of typical soil profiles (soil columns)[14].

Carbon stock of wetland soil is 350 – 535 Gt (C), accounting for 20% to 25% of global carbon stock[15]. Organic carbon density of wetland soil is generally high. Pan Genxing[16] estimated that average organic carbon density of wetland soil is 14.1 to 60.0 kg/m^2, which is far higher than average national level. Ma Xuehui *et al.*[17] estimated that carbon density of wetland soil in Sanjiang Plain is 13.9 – 47.3 kg/m^2. Different types of vegetation input different quantity and properties of organic carbon, accordingly influencing organic carbon pool of wetland soil. Kang Wenxing *et al.*[10] studied Dongting Lake wetland and found that the carbon density of undisturbed meadow soil is 26.05 kg/m^2, annual meadow harvested is about 18.55 kg/m^2, 23.45 kg/m^2 forest, and hydrophyte soil 20.69 kg/m^2, lower than average national level. Through the study of Wu Qin *et al.*[9], it indicates that the carbon density of Poyang Lake wetland is 3.02 – 10.19 kg/m^2, far lower than 14.40 – 66.20 kg/m^2 obtained by Zhang Wenju *et al.*[18] in the survey of Sanjiang Plain, and 56.27 – 88.90 kg/m^2 obtained by Man Xiuling *et al.*[19] in the survey of Lesser Khingan Mountains.

2.3 Aquatic carbon pool of wetland Aquatic carbon pool of wetland mainly includes hydrophyte biomass, water body and deposit carbon stock. The hydrophyte biomass is estimated by measurement and remote sensing. Dissolved organic carbon (DOC) in a lake is the largest organic carbon pool[20]. Buffam *et al.*[21] estimated the dissolved carbon pool of the lake by average water depth, average DOC and dissolved inorganic carbon (DIC). Campbell *et al.*[22] discussed the deposit organic matters and the relationship with lake characteristics influencing deposit organic matters, such as deposit amount, lake depth, sample depth, and DOC, etc. Buffam *et al.*[21] estimated that the regional deposit carbon pool is 74 – 250 Tg C taking 7.5 – 9.9 average depth of lake deposit and unit area carbon stock of 89 to 301 kg/m^2 C. Heterogeneity of deposit depth and carbon density of deposit are major factors influencing estimation of carbon stock of deposit.

3 Carbon cycle of wetland ecosystem

Carbon cycle of wetland ecosystem includes carbon fixation through photosynthesis and carbon emission through respiration: through photosynthesis, plants absorb CO_2 and form organic matters; plant residues enter organic matters after decomposition; organic matters are mineralized and generate CO_2, and produce CH_4 in anaerobic environment to be released to atmosphere. Besides, dissolved organic carbon and particulate organic carbon migrate with water, making wetland carbon participate in wider carbon cycle. Carbon fixation speed of wetland is very slow and the storage time is long. However, once wetland is dried, the carbon decomposition is very fast, so that carbon stored for a long time will be released to the atmosphere in a short time. Thus, wetland protection can effectively contain emission of greenhouse gases.

3.1 Carbon accumulation of wetland ecosystem Accumulation of wetland organic carbon is the balance between net primary productivity (NPP) and decomposition of organic matters. The vegetation of wetland has high productivity, the average NPP is about 9 t/(hm^2 · a), the maximum value is up to 20 t/(hm^2 · a). The NPP of Carex lasiocarpa in Sanjiang Plain swamp wetland is up to 13 t/hm^2 annually[17]. Water accumulation of wetland will create anaerobic environment, plant residues decompose very slowly in original place or after migration, finally form the carbon storage layer. According to reports of Svensson and Rosswall[23], about 30% – 40% of NPP of peat wetland vegetation is stored in peat layer. The organic carbon brought in and out of wetland ecosystem accounts for certain proportion in input and output of total organic carbon.

3.2 Carbon emission of wetland ecosystem

3.2.1 Emission of wetland CO_2. In condition of water accumulation, decomposition rate of wetland organic carbon is low, which is CO_2 sink. However, after water is discharged, the decomposition rate of organic matters in aerobic soil becomes larger than accumulation rate, wetland will become source of CO_2[24]. The flux of soil CO_2 in wetland is manifested as respiration rate of soil. Generally, emission of soil CO_2 mainly comes from decomposition of organic matters and respiration of plant roots, and little comes from respiration of soil animals[25]. Emission of soil CO_2 is an essential output approach of soil carbon pool and also important source of atmosphere CO_2[26]. Thus, the study on flux of soil CO_2 is a key part of researches about carbon cycle of wetland. Heterogeneity of soil CO_2 flux is connected with plant composition, meteorological condition and soil environmental factors, inconsistency of these conditions may lead to difference in soil CO_2 flux. Researches have shown that soil CO_2 flux of wetland has high time – space variability, not only obvious seasonal changes, but also daily changes[27].

3.2.2 Emission of wetland CH_4. CH_4 is a major greenhouse gas and also an important approach for output of wetland soil carbon. Wetland is the largest emission source of CH_4, and its contribution to global CH_4 emission is up to 15% – 40%[28]. Recent researches indicate that the emission of CH_4 in wetland has increased to 180 Tg/(CH_4 · a)[29]. Emission of CH_4 in wetland needs CH_4 generation, oxidation, and transmission, involving corresponding physical, chemical and biological processes, thus it is closely connected with regional climate and soil environment. Differences in physical and chemical properties of wetland soil, hydrological condition, vegetation type and climatic condition of wetland lead to great time – space variability in CH_4 emission of wetland[30]. For example, from observation of paddy field ecosystem, we found that the methane emission in rice growing season has three peak values[31]. In day and night changes, the peak value will appear in afternoon[32].

4 Prospect of researches on carbon cycle of Dongting Lake wetland

Dongting Lake is situated in north of Hunan Province, fed by four major rivers: Xiang, Zi, Yuan and Li rivers, and is the second largest fresh water lake in China. Dongting Lake wetland mainly includes various ecosystems in Dongting Lake alluvial plain. With the area of 1.87×10^4 km^2, it is one of the most important wetlands in China. In recent 100 years, the area of Dongting Lake shrinks gradually, silt deposit area gradually increases, leading to sharp decrease of ecological functions. In recent years, the implementation of Three Gorges Project, reclaiming farmland to lake and ecological restoration exerts great influence on wetland environment of Dongting Lake and land use types. Besides, its carbon storage and carbon cycle situations also have great changes. However, there are few researches about these.

4.1 Carbon storage and carbon cycle of Dongting Lake wetland Since the implementation of Three Gorges Project and reclaiming farmland to lake, alternation and conversion of Dongting Lake wetland not only influence changes in area of different wetland types, but also influence changes in carbon density[10,33]. Zhang Huaiqing *et al.*[34] found that although some fields were returned to the lake in 1996 – 2004, wetland of Dongting Lake still shrank for 3 753.99 km^2, including 1213.19 km^2 natural wetland and 2 540.80 km^2 artificial wetland. Deng Fan *et al.*[35] found that beach vegetation distribution and area of Dongting Lake also changed significantly in 1993 – 2010. Forest beach area increased about 367.88 km^2 and became the major beach type, reed beach area reduced 44.09 km^2, and grass beach area increased about 2.99 km^2. In future, researches should focus on area of wetland and changes of the area, determination of reference point, characteristics of carbon density, and space variability. In recent 50 years, water body area of Dongting Lake gradually shrank, the reduction area is up to 1 460 km^2[36]. Volume of water body of Dongting Lake, content characteristics of dissolved organic matter, depth of bottom deposit, and carbon content characteristics are difficult points in estimating carbon pool of the water body. To estimate carbon stock of Dongting Lake wetland, it is necessary to combine field survey with remote sensing information, and long-term data to build models.

On the whole, research on carbon cycle of Dongting Lake wetland needs focusing on its productivity, carbon-fixation potential, accumulation mechanism of organic carbon, emission of greenhouse gases, as well as response of ecosystem. In addition, it is necessary to grasp the influence of input-output flux of carbon cycle of different types of wetlands, composition of organic carbon, and distribution of organic carbon in wetland deposit profile, hydrological and geological conditions of Dongting Lake on accumulation of organic carbon[37].

4.2 Factors influencing carbon cycle of Dongting Lake wetland

4.2.1 Ecological conditions. Dongting Lake serves as the main flood – basin of the Yangtze River and its ecological function is greatly influenced by four above said rivers and Yangtze River. Carbon cycle of Dongting Lake wetland is mainly affected by silt deposit, input of organic matters and water volume. After implementation of Three Gorges Project and reclaiming farmland to lake, silt deposit becomes the major reason for beach wetland of Dongting Lake. Annual average sediment yield of Dongting Lake is $12\ 325 \times 10^4$ t, the sediment of four rivers is $4\ 351 \times 10^4$ t, accounting for 35%, and the sediment of natural lake area is $7\ 999 \times 10^4$ t, accounting for 65%[38]. Uneven sediment accumulation of silt inevitably leads to difference in development and evolution of wetland[39]. Areas with higher elevation have more sediment accumulation of silt; on the contrary, areas with lower elevation have less sediment accumulation of silt. In Dongting Lake wetland, water-flooding frequency increases with reduction of elevation. Thus, in high (but not very high) elevation area, the restoration environment is not favorable for mineralization and decomposition of organic carbon, and accumulation is easy to occur, leading to relatively high of organic carbon. In high elevation area, organic carbon of soil is obviously low in surface layer, mainly because organic carbon in soil is fully exposed to air, soil temperature and humidity conditions get improved, and then decomposition of organic carbon is accelerated[40]. This is also one of major reasons for variation in organic carbon content of wetland in the same evolution period. In addition, the more silt carried by flowing water, the more likely it will accelerate evolution from grass to reed, leading to loss of organic carbon accumulated in wetland and increasing emission of wetland carbon to atmosphere. Therefore, strengthening water and soil conservation of middle and upper reaches of Yangtze River and Dongting Lake basin and reducing silt carrying of flowing water are of great realistic significance to maintaining and enhancing carbon sink function of Dongting Lake wetland.

Organic matters in the lake come from internal and external sources. External organic matters inputting to Dongting Lake increases decomposition of microorganisms and the possibility of carbon release, and its decomposition residues deposit at the lake bottom and accordingly increase the carbon stock. Oil and phenol types organic chemicals input to Dongting Lake in 2005 reached 713.078 t[41]. Organic matters transmitted into the lake also include oxygen-demanding organic matters (COD), coming from river run-off, industrial blowdown, domestic wastewater, animal and human excreta, and surface run-off, etc. In 2005, the total COD flowing to Dongting Lake amounted to 3.1705 million tons[41]. After organic matters enter the lake, most organic matters are decomposed by microorganisms into CO_2 and released, and some large molecules form humus and deposit at the lake bottom[42].

The completion of Three Gorges Project brings huge changes of water volume of Dongting Lake. Data of hydrographic authority of Hunan Province indicate that water level in Lingji Station dropped to the lowest value 21.7 m in the 60 years. Li Jingbao *et al.* [43], based on hydrological data in 1951 – 2008, analyzed water volume after operation of Three Gorges Dam, the average annual inflow run-off of Songzi, Taiping, and Ouchi riverfronts reduced about 24.4%, average annual water volume in flood season of Dongting Lake reduced about 20.2%, leading to seasonal water shortage in consecutive years. Besides, after completion of Three Gorges Project, silt of Yangtze River is reduced, and clear water flows to low reaches, so the water flowing from Yangtze River to Dongting Lake is also reduced. As a result, Dongting Lake enters the dry season ahead of time, and the dry season prolongs and water level is continuously low. In addition to reservoirs in upper reaches of the four rivers and Xiang River Water Control Project, water flowing from four rivers to Dongting Lake also decreases, consequently worsens the water shortage of wetland of Dongting Lake.

4.2.2 Land use types. From 1998, Dongting Lake area launched the project of "leveling embankment for flood running and returning field to the lake", in order to restore and improve ecological functions of Dongting Lake wetland. In non-flood storage years, there are different types of land use and the storage of organic carbon is also different. Wang Yuerong *et al.* [44] studied organic matters of soil in 5 types of land use, and obtained the range of content change is 3.40 – 32.32 g/kg, and the surface soil is paddy field (32.32 g/kg) > dry land (26.48 g/kg) > garden land (25.52 g/kg) > waste land (22. 23g/kg) > forest land (19.41 g/kg). After the implementation of the project of "leveling embankment for flood running and returning field to the lake", land use types mainly include restoration of natural water, planting poplars and planting reeds. Different land use types have different productivity and different carbon fixation levels. Ren Bo *et al.* [45] found the significant difference in productivity between these three types, among which poplar mode has the highest productivity. The study of Liu Na *et al.* [46] indicates that after retuning field to the lake, soil environment is restored close to natural wetland system. In the three types, retuning field to the lake has the best restoration effect, while poplar planting has better effect than artificial reeds and has certain accumulation of soil organic matters. The study of Kang Wenxing[47] shows that planting poplars in Carex land results in loss of organic carbon at 40 cm or even below soil layer. In 8 years after poplar planting, the loss of organic carbon reached 33.89 t/hm^2, and about 40.02% organic carbon of surface soil is lost in atmosphere. Tang Jie *et al.* [48] found that the respiration of soil is reed land > poplar field > farmland in different land use types.

Wetland of Dongting Lake is not only influenced by the Three Gorges Project and Dongting Lake basin, but also influenced by changes in land use types after returning field to the lake. Therefore, researches of carbon cycle of Dongting Lake wetland should consider changes of the wetland itself and the influence of Dongting Lake river system and Yangtze River, to maintain ecological functions and carbon sink function of the wetland.

5 Conclusions and discussions

Past researches of carbon stock focus on vegetation, soil, water body, and deposit. In future, we should shift our focus to regional wetland and take overall consideration of carbon stock. Specifically, we should put close attention to soil depth, depth of sedimentary facies, seasonal changes of water body. These are helpful for accurately estimating carbon stock. We can combine sample plot survey and remote sensing images, and select proper image processing technologies, to improve estimation accuracy of carbon stock. Besides, we can care about influence of dry and wet alternation on release and accumulation of wetland carbon by dynamic observation, especially the influence of seasonal aridity on mineralization of soil organic matters. In addition, we should obtain laws of emission of greenhouse gases, including CO_2, CH_4, and N_2O with reference to greenhouse effect of CO_2, to comprehensively evaluate greenhouse effect of greenhouse gases.

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