Bulletin of Chinese Academy of Sciences 中国科学院院刊

Volume 36 | Issue 3 Article 2

3-20-2021

Blue Carbon Sink Function of Chinese Coastal Wetlands and Carbon Neutrality Strategy

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Abstract

Coastal wetlands are the main body of the coastal "blue carbon (C)" ecosystem, and their "blue C" and ecosystem service function are important ocean-based climate change governance methods, which is a "nature-based solution". Chinese coastal wetlands are dominated by salt marshes, with little area of mangroves, while the area of unvegetated tidal flats is large. According to conservative estimation, the current C sequestration of coastal wetlands through sediment burial in China reaches to 0.97 Tg C·a-1, and would increase to 1.82-3.64 Tg C·a-1 at the end of this century. To achieve the commitment of "C neutrality" in 2060, China should strengthen scientific research on coastal wetlands, protect the integrity of the structure and function of the existing coastal wetland ecosystems, stop destructive coastal wetlands development activities, and actively and steadily promote the ecological restoration of coastal wetlands, restore and enhance its "blue C" function, and benefit from C sink gains while protecting the nature.

Keywords

coastal wetland, carbon (C) neutrality, C sequestration, blue carbon, mangrove, salt marsh, tidal flat, restoration

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Citation: WANG Faming, TANG Jianwu, YE Siyuan, LIU Jihua. Blue Carbon Sink Function of Chinese Coastal Wetlands and Carbon Neutrality Strategy [J]. Bulletin of Chinese Academy of Sciences, 2021 (3): 241–251.

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Abstract: Coastal wetlands are the main body of the coastal blue carbon (C) ecosystem. Improving the blue C sink of coastal wetlands is an important ocean-based climate change governance method, which is a nature-based solution. Chinese coastal wetlands are dominated by salt marshes, with a small area of mangroves while a large area of unvegetated tidal flats. According to conservative estimation, the current C sequestration of coastal wetlands through sediment burial in China reaches 0. 97 Tg C·a^{-1} and would increase to 1.82–3.64 Tg C·a^{-1} at the end of this century. To achieve the commitment of C neutrality in 2060, China should strengthen scientific research on coastal wetlands, protect the integrity of the structure and function of the existing coastal wetland ecosystems, stop destructive development activities on coastal wetlands, and actively and steadily promote the ecological restoration of coastal wetlands, restore and enhance its blue C function, and benefit from C sink gains while protecting the nature.
DOI: 10.16418/j.issn.1000-3045.20210215101-en

Keywords: coastal wetland; carbon (C) neutrality; C sequestration; blue carbon; mangrove; salt marsh; tidal flat; restoration

Coastal wetlands include salt marshes and mangroves. Affected by periodic tidal inundation, coastal wetlands display a powerful carbon sink function, playing an important role in reducing carbon dioxide (CO_2) concentration and mitigating global climate change [1]. The carbon sequestered by coastal wetlands and seagrass beds is called coastal blue carbon [2], corresponding to green carbon of terrestrial vegetation. The net carbon flux (difference between influx and efflux) from the atmosphere by oceans is 2.3 Pg C·a^{-1} per year, and that by terrestrial ecosystems is 2.6 Pg C·a^{-1} [3]. It is traditionally believed that blue carbon is stored mainly through physical carbon solubility pump (dissolution of atmospheric CO_2 into seawater), biological pump (uptake and conversion of CO_2 by plants through photosynthesis, followed by deposition to the seafloor), and marine carbonate pump (uptake, conversion and release of carbon by marine organisms such as shellfish and coral reefs) on different time scales [4]. According to UN assessment [5], half of the carbon sequestered by living marine organisms is in the coastal blue carbon ecosystem. Coastal wetland, as an important type of coastal blue carbon ecosystems [6], has a huge carbon sequestration capacity [2], providing nature-based solutions and serving an important ocean-based climate change governance approach. While mitigating greenhouse gas emissions, coastal wetlands can bring economic and social benefits to coastal countries and even the world. The annual carbon burial per square kilometer of coastal wetland is estimated to be 0.22 Gg C, equivalent to 3.36×10^5 L carbon dioxide (CO_2) emitted from gasoline combustion [7]. Therefore, assessing the carbon sink capacity, carbon sequestration potential, and ecosystem services of coastal wetlands is essential for drafting the measures for emission reduction and carbon sink gains. It serves as a theoretical basis of government action plans to address climate change as well as a springboard for China to achieve the goal of carbon neutrality.

1 Blue carbon sequestration and its mechanism of in coastal wetlands

Coastal wetlands prevail over terrestrial ecosystem in the rapid and long-term carbon sequestration [2,8,9]. The carbon released by plant and soil respiration in terrestrial ecosystem keeps increasing as plants grow and soil organic matter accumulates. Therefore, the carbon sequestration capacity of terrestrial ecosystem will be saturated in decades or centuries.

Received: 2021-3-6
Supported by: National Natural Science Foundation of China (31870463, 31670621); Project of Youth Innovation Promotion Association, CAS (2021347); Key Project of Southern Marine Science and Engineering Guangdong Laboratory (Guangzhou) (GML2019ZD0408); Science Foundation for Distinguished Young Scholars of Guangdong Province.

Then, the carbon absorbed by plants through photosynthesis is balanced with the carbon released by the respiration of plants, microorganisms and animals in the system, thus leading to zero net carbon sequestration capacity [10]. The litter of plants in coastal wetlands will be deposited in the soil. Unlike the sedimentary organic matter in terrestrial ecosystem, the decomposition of sedimentary organic matter in coastal wetlands is greatly moderated by tidal reciprocation. As sea level rises, sediments in coastal wetlands will be accumulated and buried into deeper soil layers, which is unfavorable to the degradation of organic matter. The carbon in the sediments without being released back to the atmosphere will remain stable in hundreds to tens of thousands of years, capable of being steadily and constantly stored [2]. In addition, the presence of large amounts of sulfate ions in seawater can suppress the emissions of methane (CH_4) in coastal wetlands compared with that in freshwater wetlands. Obviously, coastal wetlands are better in carbon sequestration, with their carbon burial rate per unit area tens to thousands of times higher than that of terrestrial forests [2]. Therefore, in the long term, compared with terrestrial ecosystem, coastal wetlands exhibit stronger carbon sequestration and better ecosystem services. Therefore, coastal wetlands are an important channel for humans to address the current climate change [11].

The carbon sequestration of coastal wetlands can be measured by the carbon burial rate and the exchange of atmospheric CO_2 with dissolved inorganic carbon (DIC), dissolved organic carbon (DOC), and particulate organic carbon (POC) in the seawater through tidal action [4] (Figure 1). On a global scale, salt marshes cover an area of 6.23×10^4 km^2 while mangroves cover an area of 14×10^4 km^2 [12–14]. According to the global distribution of coastal salt marshes and mangroves as well as the studies of organic matter deposition rates in coastal areas, Wang et al. [15] estimated global carbon burial rate of salt marshes and mangroves to be 53.65 Tg C·a^{-1}, equivalent to 196.71 Tg CO_2·a^{-1}, which was 0.6% of the annual emissions by human activities. The carbon burial rate of coastal wetland per unit area was about 15 folds and 50 folds of the carbon sequestration rate of terrestrial ecosystem and marine ecosystem, respectively, being particularly high. Moreover, this figure is only for the vertical carbon burial rate, and much carbon will be transported to the ocean in the form of DIC, POC and DOC through tidal movement and the exchange with the ocean, which due to methodological limits, has been rarely reported. However, it has been shown that the inorganic carbon transported from the coastal wetlands into the ocean by tides far exceeds the deposited organic carbon [16]. It indicates that the actual annual carbon sequestration capacity of coastal wetlands is far beyond the conventionally estimated carbon burial rate.

2 Hot spots of research on blue carbon in coastal wetlands

Since 2011, the research on the carbon sequestration capacity of coastal blue carbon ecosystems has gradually become an hot topic [2,17], and China has founded several blue carbon research projects in recent years [8,18]. Macreadie et al. [19] summarized 10 hot topics in blue carbon research, nine of which were related to the blue carbon of coastal wetlands. They are listed below. (1) How does climate change affect the carbon accumulation of blue carbon system? (2) How does human disturbance affect the carbon accumulation of blue carbon system? (3) What are spatial and temporal patterns and distribution of blue carbon ecosystem? (4) How does organic and inorganic carbon cycling affect carbon emissions? (5) How to estimate the source of carbon in blue carbon system? (6) What are the factors that affect the rate of carbon burial in blue carbon system? (7) What is the rate of greenhouse gas exchange between blue carbon system and the atmosphere? (8) How to reduce the uncertainty in blue carbon estimation? (9) How to maintain and enhance the sequestration of blue carbon? More than hot research topics at present, these issues lead the future research on coastal wetlands.

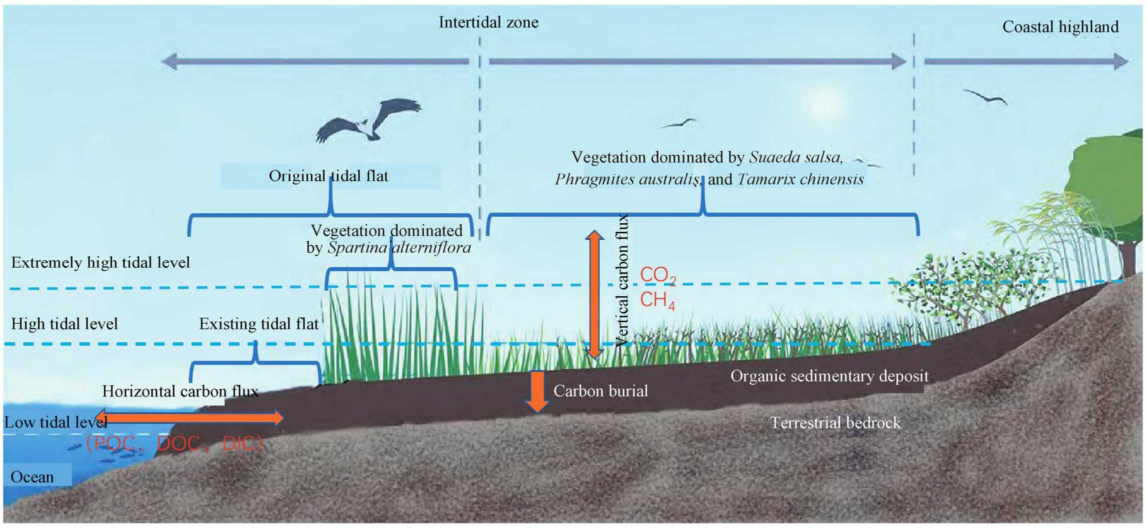

Figure 1 Main types of Chinese coastal wetlands and C sequestration mechanisms

In general, the amount, rate, process, and ecological services of carbon sequestration in coastal wetlands remain to be explored [20]. Although the concept of blue carbon was first proposed by American scientists, American researchers are not well-informed about the rate of blue carbon sequestration of their domestic coastal wetlands. Most reports have focused on the carbon stock of coastal wetlands, without systematic summary of carbon fluxes and ecosystem service functions [21–23]. To fill this gap, Chinese researchers employed carbon deposition data of coastal wetlands and the wetland survey data to systematically estimate the current national-wide carbon burial capacity of coastal wetlands in the United States [24]. Based on the climate model prediction data of the Intergovernmental Panel on Climate Change (IPCC) and the simulation data of global coastal wetland area, the empirical model of carbon sequestration rate with climate factors was established. A vision was proposed that the carbon burial capacity of global coastal wetlands would keep increasing by the end of the 21st century [15]. This is the first systematic estimation and prediction of the blue carbon burial rates in coastal wetlands on the national scale (US) and the global scale. Unfortunately, systematic model prediction of the carbon sequestration function of coastal wetlands in China remains vacant [25].

Coastal wetlands are sensitive and vulnerable to global change. How their carbon sequestration responds to human activities and environmental changes is a hot topic in blue carbon research. On one hand, habitat destruction and environmental pollution caused by human activities have seriously affected the health and thus the carbon sequestration of coastal wetlands [26]. In recent decades, the demands spurred by growing population and booming economic development have led to dramatic change in coastal land use around the globe [21,27]. The past century has witnessed the significant reduction in the carbon sink and carbon reserve of coastal wetlands. Human activities and environmental changes, such as enclosing tideland for cultivation, sea reclamation, and shore protection embankment, as well as changes in environmental factors such as the increases in nutrient salts and temperature, lead to the continuous decrease in carbon sink in coastal wetlands [8]. In the United States, for example, frequent human activities have declined the coastal wetland area by more than 50% compared with that before industrial revolution [28,29]. In the wake of human awareness of the carbon sink function of coastal wetland ecosystems [2], how to conserve coastal wetland resources and effectively restore damaged wetlands has become a major issue in ecological restoration [11,30]. During the restoration of coastal wetlands, significant changes will take place in carbon cycle. Effective ecological restoration will reduce wetland CH_4 emissions and promote plant growth [31], thereby increasing the rate of organic matter deposition and thus the carbon sequestration and ecosystem service functions of wetlands [10,29,32]. In addition to the change in land use caused by human activities, coastal wetlands in the context of global climate change are subjected to eutrophication, temperature rise, and sea-level elevation, which changes plant growth and succession, especially alters the production and decomposition associated with carbon cycle, ultimately affecting the carbon sequestration [33]. A 10-year simulation experiment on nitrogen fertilizer addition in salt marshes of the United States confirmed that the increase in seawater nitrogen led to degradation of salt marshes [34], which further led to the reduction of their carbon sink function. Sea-level rise is another major factor affecting the carbon sink of coastal wetlands. Normally, sea-level rise results in organic matter deposition. However, when the rate of sea-level rise exceeds the deposition rate of coastal wetlands, these wetlands will be gradually inundated by seawater [35], leading to the failure of continuous carbon sequestration [36].

3 Carbon sink of coastal wetlands in China

China has 1.8×10^4 km of continental coastline and over 2×10^6 km^2 of continental shelf, with various types of wetlands. This paper focuses on salt marshes, mangroves, and tidal flats.

3.1 Salt marshes

Salt marshes have strong carbon sequestration capacity, with an average carbon burial rate of 168 g $C \cdot m^{-2} \cdot a^{-1}$ in the sediments [15]. Salt marshes are the largest type of coastal blue carbon ecosystem in China. The statistics of their total area vary due to taxonomic reasons. Zhou et al. [37] estimated the salt marsh area in China to be 1 207–3 434 km^2. According to the global remote sensing data of salt marshes recognized by United Nations Environment Programme [14], the area of salt marshes in China was 5 448 km^2 [14]. The survey data obtained by Ye [38] in 2017 showed that the total area of vegetated coastal wetlands and tidal flats in China amounted to 9 862 km^2. However, the latest nation-wide remote sensing map of wetlands in China showed that the area of salt marshes was only 2 979 km^2 [39]. The salt marshes in China are mainly distributed in the Bohai Bay, the coasts of Jiangsu Province and the Yangtze River estuary, and the tropical and subtropical regions in southern China (Table 1). They mainly grow salt-tolerant plants such as *Suaeda salsa*, *Phragmites australis*, and *Spartina alterniflora* (Figure 1). *S. alterniflora* is an alien species originating from North American salt marshes. With strong adaptability and tolerance, it is the dominant plant in North American salt marshes. In the 1980s, *S. alterniflora* was introduced to China for land creation with silt and shore protection in coastal areas. Nevertheless, it gave rise to ecological problems such as the invasion of barren wetlands and the threat to native plants and waterfowl habitats [40]. As of 2015, the area of *S. alterniflora*-dominated wetlands in China reached 546 km^2, an expansion of 502 km^2 from that in 1990. *S. alterniflora* is mainly distributed in Jiangsu, Zhejiang, Fujian, and Shanghai [41]. These newly colonized wetlands encroached 93% of the original coastal tidal flats [41].

Table 1 Distribution and estimated C accumulation rate of coastal wetlands along coastlines of China in 2015

Provincial-level administrative region	Area (km^2)				Carbon burial capacity (Gg C·a^{-1})			
	Salt marsh	Mangrove	Tidal flat	Total	Salt marsh	Mangrove	Tidal flat	Total
Liaoning	974.73	0.00	0.01	974.73	162.78	0.00	0.00	162.78
Hebei	103.47	0.00	83.05	186.51	17.28	0.00	13.95	31.23
Tianjin	189.69	0.00	0.00	189.69	31.68	0.00	0.00	31.68
Shandong	421.34	0.00	342.08	763.42	70.36	0.00	57.47	127.83
Jiangsu	465.98	0.00	62.77	528.75	77.82	0.00	10.55	88.36
Shanghai	602.66	0.00	109.81	712.47	100.64	0.00	18.45	119.09
Zhejiang	76.60	1.06	217.40	295.06	12.79	0.21	36.60	49.60
Fujian	51.21	8.27	282.85	342.34	8.55	1.60	48.54	58.70
Guangdong	53.61	92.05	348.07	493.73	8.95	17.86	64.19	91.00
Guangxi	8.98	112.51	697.32	818.81	1.50	21.83	133.94	157.27
Hainan	15.67	36.30	50.31	102.28	2.62	7.04	9.37	19.02
Taiwan	15.41	7.36	180.75	203.53	2.57	1.43	31.89	35.89
Hong Kong	0.02	1.04	0.02	1.09	0.00	0.20	0.00	0.210
Macao	0.00	0.00	0.07	0.07	0.00	0.00	0.01	0.010
Total	2979.36	258.60	2374.51	5612.47	497.55	50.17	424.96	972.68

Note: The distribution data originated from Mao et al. [39] and C accumulation rate was cited from Wang et al. [15].

Using remote sensing data of salt marshes and the measured carbon burial rate of coastal wetlands, Wang et al. [15] estimated that the carbon burial rate of salt marshes in China was 1.19 Tg C·a^{-1}, larger than the previous estimate of 0.26–0.75 Tg C·a^{-1} [37] and the recent estimate of 0.16 Tg C·a^{-1} by Fu et al. [42]. The difference is mainly caused by the larger area (5 448 km^2) of salt marshes in China than that of other data sources. In this paper, based on conservative estimate of wetland area (2 979 km^2), the annual carbon burial rate of salt marshes in China is 0.50 Tg C·a^{-1} (Table 1).

3.2 Mangroves

Mangroves grow mainly in tropical and subtropical coastal intertidal zones. On a global scale [15], the total area of mangroves is about 1.4 × 10^5 km^2 , larger than the salt marsh area of 6.23 × 10^4 km^2. The annual carbon burial rate of global mangrove sediments [15] is 38.3 Tg C·a^{-1}, much greater than that (12.6 Tg C·a^{-1}) of salt marshes. Meanwhile, mangroves can export 21 Tg C·a^{-1} of POC and 24 Tg C·a^{-1} of DOC to the adjacent sea area [12]. Therefore, mangroves are considered the most effective coastal ecosystems for carbon sequestration.

Globally speaking, China's mangroves are located at the northern edge of global mangrove distribution area, and they are mainly located in Guangdong, Guangxi, Hainan, and Fujian. Wang et al. [15] estimated that the average carbon burial rate of global mangroves was 194 g C·m^{-2}·a^{-1}, while that in China was about 0.05 Tg C·a^{-1}, comparable to that in other studies [37,42]. It is much smaller than the carbon burial rate of China's salt marshes, mainly because of the too small area of mangroves existing in China. According to the remote sensing data, the area of mangroves in China was only 171 km^2 in 2010 [13]. However, this figure is controversial. The total area of mangroves in China in 2015 obtained by remote sensing mapping by Mao et al. [39] was 259 km^2. According to the latest data from the National Forestry and Grassland Administration, mangroves in China have been recovering rapidly over the past 10 years. The total area in 2020 is 289 km^2, of which more than 70 km^2 are mangroves recently created and restored. However, even according to the recent data on mangrove area, the current mangrove area in China is only about 1/10 of the historical high (about 2 500 km^2) [43,44]. The room for restoration remains large.

3.3 Tidal flats

Tidal flats, another important type of coastal ecosystems, mainly include mudflat, sandy beach, and bedrock coast [45], among which mudflat has a considerable carbon burial capacity [46,47]. As remote sensing data varies, the area of coastal tidal flats in China varies greatly. A nation-wide wetland distribution map drawn by Mao et al. [39] showed that the total area of mudflat in China, 2015 was 2 374 km^2 , slightly lower than the total area of salt marshes in China. Recent satellite remote sensing showed that the area of coastal tidal flats (including mudflats, rocky beaches, sandy beaches, and some shallow seas) in China was 5 379–8 588 km^2 [48–50]. These differences are attributed to the sources of satellite images and shooting frequency [50]. In general, the area of coastal tidal flats in China is very large, even larger than the total area of salt marshes and mangroves combined. Coastal tidal flats are dominated by mudflats, which have a high sediment burial rate and strong carbon sequestration potential. The buried carbon in these mudflat sediments is mainly from the surrounding salt marshes and mangroves as well as the deposition of POC and mineral-bound carbon from seawater [51], and therefore should be included in the calculation of blue carbon sink of coastal wetlands. It has been proved that the sedimentation rate and carbon burial capacity of mudflats are equivalent to those of the surrounding salt marshes and mangroves [46,52–54]. On the basis of the most conservative data of distribution area of coastal tidal flats [39] and the carbon burial rates of their surrounding salt marshes and mangroves [24], we estimate that the lower limit of carbon burial rate of coastal tidal flats in China is about 0.42 Tg $C\cdot a^{-1}$, much higher than the carbon burial capacity of mangroves and second only to that of salt marshes (Table 1).

In addition, the coastal tidal flats in China are confronted with the invasion of *S. alterniflora*. Over the past three decades, nearly 467 km^2 of tidal flats have evolved into the salt marshes dominated by *S. alterniflora* [41] (Figure 1). Compared with the surrounding salt marshes and mangroves, coastal tidal flats have low net ecosystem productivity, which accounts for only 10%–20% of the former [46]. The *S. alterniflora* invasion into tidal flats increases the input of plant biomass and organic litter [55,56], and the dense coverage of *S. alterniflora* slows water flow and accelerates sediment accumulation, thus increasing sedimentation rate [57]. In addition, *S. alterniflora* absorbs a large amount of nitrogen, phosphorus, and other nutrient salts in the tidal flats, which can reduce the input of terrestrial nutrient salts to offshore eutrophic sea areas and improve offshore primary productivity. Overall, the total carbon sink of coastal tidal flats invaded by *S. alterniflora* increases [58–60]. The invasion is conducive to the carbon sequestration capacity of coastal wetlands in China [40]. However, the comprehensive service of the colonized ecosystem remains to be estimated.

4 Development direction and policy recommendations

Coastal wetlands have a strong ecosystem service function and high carbon sink, as well as powerful self-recovery capacity [26]. Despite the challenges of human disturbance, sea-level rise, and climate change, the total area of global coastal wetlands is expected to increase to some extent by the end of the 21st century [61]. Its overall carbon sequestration capacity, especially the carbon burial rate, will be improved [15]. Because of the rapid sedimentation [42], the total area, carbon sink, and services of China's coastal wetlands will still increase by the end of the 21st century in the absence of human destruction and disturbance of natural shorelines [61]. The results of model prediction [15] showed that the carbon burial capacity of coastal salt marshes and mangroves in China would increase to 1.82–3.64 Tg $C\cdot a^{-1}$ by the end of the 21st century.

However, the total area of coastal wetlands in China is limited. Land development activities such as beach reclamation, fish and shrimp farming, urbanization, and industrialization in the coastal zone in the past decades have drastically reduced the area of coastal wetlands. The carbon sequestration and carbon sink potential of coastal wetlands have thus decreased [8]. From 1975 to 2017, the decline rate of natural wetlands in China was 53.9% [38]. Therefore, how to effectively restore coastal wetlands, increase the area of wetlands, reduce the damage to the natural shorelines, improve their natural recovery capacity, and enhance the ecosystem service function of existing coastal wetlands is of great significance to the restoration and improvement of the blue carbon function of coastal wetlands in China.

At present, China finds it urged to strengthen the research, protect the ecosystem integrity and services, and stop the destructive development activities of coastal wetlands. These measures will help avoid the rapid loss of blue carbon function, promote the ecological restoration of coastal wetlands, and restore and enhance its blue carbon function. We can benefit from the carbon sink gain while protecting nature, and make the coastal wetland blue carbon contribute to the carbon neutral strategy. Therefore, we put forward the following recommendations to be strengthened in the subsequent research and management policy of coastal wetlands.

(1) Establishing a field observation and research network for coastal ecosystems. Typical coastal ecosystems should be selected for the establishment of field observation and research stations incorporated into the national field research network. Through the networked observation of multiple sites, we will gain an in-depth understanding of the ecosystem structure and services of coastal wetlands, expound the spatial and temporal patterns of carbon burial rate and greenhouse gas emissions and their mechanisms, and conduct systematic research on the community types with strong carbon sequestration capacity.

(2) Systematically quantifying the blue carbon sequestration function of coastal wetlands in China. By simulating human activities and climate change, and taking into account geographic information system (GIS) and land remote sensing data, we are expected to establish models to predict the blue carbon function and its trend in different climate change scenarios in the future. With the obtained results, we can

expound the response and adaptation mechanisms of China's coastal wetlands to future climate change and human activities, improve the understanding toward the mechanism of blue carbon sink enhancement of China's coastal wetlands and the prediction accuracy of carbon sink intensity, and highlight their comprehensive ecosystem services.

(3) Systematically researching the coastal wetlands colonized by alien species. Efforts should be made to comprehensively assess the ecological risks and negative emission effects of alien species in coastal wetlands. These species can be properly used to restore and create new salt marshes and mangroves in the areas with favorable conditions.

(4) Building a demonstration area for integrated research on the services of coastal wetlands. The systematic research on the key drivers affecting the carbon sequestration of coastal wetlands will facilitate the development of the regulations and standards for coastal wetland restoration as well as the corresponding technologies for carbon sink enhancement. We will adopt different ecological countermeasures for different types of coastal wetlands in China, maximizing their service function.

References

1 Bonan G B. Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. Science, 2008, 320: 1444–1449.

2 McLeod E, Chmura G L, Bouillon S, et al. A blueprint for blue carbon: Toward an improved understanding of the role of vegetated coastal habitats in sequestering CO_2. Frontiers in Ecology and the Environment, 2011, 9(10): 552–560.

3 IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva: IPCC, 2014.

4 Tang J W, Ye S F, Chen X C, et al.Coastal blue carbon: concept, study method and application to ecological restoration. SCIENTIA SINICA Terrae, 2018, 48 (6): 661–670 (in Chinese).

5 Blue future: Coastal wetlands can have a crucial role in the fight against climate change. Nature, 2016, 529: 255–256.

6 Lovelock C E, Duarte C M. Dimensions of blue carbon and emerging perspectives. Biology Letters, 2019, 15(3): 20180781.

7 Davis J L, Currin C A, O'Brien C, et al. Living shorelines: Coastal resilience with a Blue Carbon benefit. PLoS One, 2015, 10(11): e0142595.

8 Zhang H B, Luo Y M, Liu X H, et al. Current researches and prospects on the coastal blue carbon. SCIENTIA SINICA Terrae, 2015, 45(11): 1641–1648 (in Chinese).

9 Zhang Y, Zhao M X, Cui Q. Processes of coastal ecosystem carbon sequestration and approaches for increasing carbon sink. SCIENTIA SINICA Terrae, 2017, 47(4): 438–449 (in Chinese).

10 Wang F M, Kroeger K D, Gonneea M E, et al. Water salinity and inundation control soil carbon decomposition during salt marsh restoration: An incubation experiment. Ecology and Evolution, 2019, 9 (4): 1911–1921.

11 Chen X C, Gao R F, Huang X C, et al. Basic views and technological methods of salt marsh restoration and its progresses in implementation. Marine Environmental Science, 2016, 35(3): 467–472 (in Chinese).

12 Bouillon S, Borges A V, Castañeda-Moya E, et al. Mangrove production and carbon sinks: A revision of global budget estimates. Global Biogeochemical Cycles, 2008, 22(2): GB2013.

13 Bunting P, Rosenqvist A, Lucas R, et al. The global mangrove watch—A new 2010 global baseline of mangrove extent. Remote Sensing, 2018, 10(10): 1669.

14 McOwen C J, Weatherdon L V, Bochove J V, et al. A global map of saltmarshes. Biodiversity Data Journal, 2017, (5): e11764.

15 Wang F M, Sanders C J, Santos I R, et al. Global blue carbon accumulation in tidal wetlands increases with climate change. National Science Review, 2021, DOI: 10.1093/nsr/nwaa1296.

16 Wang Z A, Kroeger K D, Ganju N K, et al. Intertidal salt marshes as an important source of inorganic carbon to the coastal ocean. Limnology and Oceanography, 2016, 61(5): 1916–1931.

17 Howard J, Sutton-Grier A, Herr D, et al. Clarifying the role of coastal and marine systems in climate mitigation. Frontiers in Ecology and the Environment, 2017, 15(1): 42–50.

18 Jiao N Z, Wang H, Xu G H, et al. Blue carbon on the rise: Challenges and opportunities. National Science Review, 2018, 5(4): 464–468.

19 Macreadie P I, Anton A, Raven J A, et al. The future of Blue Carbon science. Nature Communications, 2019, 10(1): 3998.

20 Rogers K, Macreadie P I, Kelleway J J, et al. Blue carbon in coastal landscapes: A spatial framework for assessment of stocks and additionality. Sustainability Science, 2019, 14(2): 453–467.

21 Kirwan M L, Megonigal J P. Tidal wetland stability in the face of human impacts and sea-level rise. Nature, 2013, 504: 53–60.

22 Kirwan M L, Mudd S M. Response of salt-marsh carbon accumulation to climate change. Nature, 2012, 489: 550–553.

23 Gao Y, Yu G R, Yang T T, et al. New insight into global blue carbon estimation under human activity in land–sea interaction area: A case study of China. Earth-Science Reviews, 2016, 159: 36–46.

24 Wang F M, Lu X L, Sanders C J, et al. Tidal wetland resilience to sea level rise increases their carbon sequestration capacity in United States. Nature Communications, 2019, 10: 5434.

25 Jiao N Z, Liu J H, Shi T, et al. Implementing carbon neurality strategy for marine negative emission. SCIENTIA SINICA Terrae, 2021, 51: 1–14 (in Chinese).

26 Macreadie P I, Nielsen D A, Kelleway J J, et al. Can we manage coastal ecosystems to sequester more blue carbon? Frontiers in Ecology and the Environment, 2017, 15(4): 206–213.

27 Wang X J, Zhang H B, Han G X. Carbon cycle and "blue carbon" potential in China's coastal zone. Bulletin of Chinese Academy of Sciences, 2016, 31(10): 1218–1225 (in Chinese).

28 Gedan K B, Kirwan M L, Wolanski E, et al. The present and future role of coastal wetland vegetation in protecting shorelines: Answering recent challenges to the paradigm. Climatic Change, 2011, 106(1): 7–29.

29 Emery H E, Fulweiler R W. Incomplete tidal restoration may lead to persistent high CH_4 emission. Ecosphere, 2017, 8(12): e01968.

30 Kroeger K D, Crooks S, Moseman-Valtierra S, et al. Restoring tides to reduce methane emissions in impounded wetlands: A new and potent Blue Carbon climate change intervention. Scientific Reports, 2017, 7: 11914.

31 Wang F M, Eagle M, Kroeger K D, et al. Plant biomass and rates of carbon dioxide uptake are enhanced by successful restoration of tidal connectivity in salt marshes. Science of the Total Environment, 2021, 750: 141566.

32 Drexler J Z, Krauss K W, Sasser M C, et al. A long-term comparison of carbon sequestration rates in impounded and naturally tidal freshwater marshes along the Lower Waccamaw River, South Carolina. Wetlands, 2013, 33(5): 965–974.

33 Spencer T, Schuerch M, Nicholls R J, et al. Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. Global and Planetary Change, 2016, 139: 15–30.

34 Deegan L A, Johnson D S, Warren R S, et al. Coastal eutrophication as a driver of salt marsh loss. Nature, 2012, 490: 388–392.

35 Kirwan M L, Guntenspergen G R, D'Alpaos A, et al. Limits on the adaptability of coastal marshes to rising sea level. Geophysical Research Letters, 2010, 37(23): L23401.

36 Morris J T, Sundberg K, Hopkinson C S. Salt marsh primary production and its responses to relative sea level and nutrients in estuaries at Plum Island, Massachusetts, and North Inlet, South Carolina, USA. Oceanography, 2013, 26(3): 78–84.

37 Zhou C H, Mao Q Y, Xu X.Preliminary analysis of C sequestration potential of blue carbon ecosystems on Chinese coastal zone. Science in China (Series C), 2016, 46(4): 475–486 (in Chinese).

38 Ye S Y. Wetlands: life blood of the earth. Beijing: Science Press,2021 (in Chinese).

39 Mao D H, Wang Z M, Du B J, et al. National wetland mapping in China: A new product resulting from object-based and hierarchical classification of Landsat 8 OLI images. ISPRS Journal of Photogrammetry and Remote Sensing, 2020, 164: 11–25.

40 Xie X F, Sun X M, Wu T, et al.Impacts of *Spartina alterniflora* invasion on coastal wetland ecosystem: Advances and prospects. Chinese Journal of Applied Ecology, 2020, 31(6): 2119–2128 (in Chinese).

41 Mao D H, Liu M Y, Wang Z M, et al. Rapid invasion of *Spartina al-*

terniflora in the coastal zone of Mainland China: Spatiotemporal patterns and human prevention. Sensors, 2019, 19(10): 2308.
42 Fu C C, Li Y, Zeng L, et al. Stocks and losses of soil organic carbon from Chinese vegetated coastal habitats. Global Change Biology, 2021, 27(1): 202–214.
43 Fan H Q, Wang W Q. Some thematic issues for mangrove conservation in China. Journal of Xiamen University (Natural Science),2017, 56(3): 323–330 (in Chinese).
44 Liao B W, Zhang Q M. Area, distribution and species composition of mangroves in China. Wetland Science, 2014, 12(4): 435–440 (in Chinese).
45 Murray N J, Phinn S R, DeWitt M, et al. The global distribution and trajectory of tidal flats. Nature, 2019, 565: 222–225.
46 Lin W J, Wu J H, Lin H J. Contribution of unvegetated tidal flats to coastal carbon flux. Global Change Biology, 2020, 26(6): 3443–3454.
47 Xia S P, Wang W Q, Song Z L, et al. *Spartina alterniflora* invasion controls organic carbon stocks in coastal marsh and mangrove soils across tropics and subtropics. Global Change Biology, 2021, DOI: 10.1111/gcb.15516.
48 Wang X X, Xiao X M, Zou Z H, et al. Mapping coastal wetlands of China using time series Landsat images in 2018 and Google Earth Engine. ISPRS Journal of Photogrammetry and Remote Sensing, 2020, 163: 312–326.
49 Wang X X, Xiao X M, Zou Z H, et al. Tracking annual changes of coastal tidal Flats in China during 1986–2016 through analyses of Landsat images with Google Earth Engine. Remote Sensing of Environment, 2020, 238: 110987.
50 Jia M M, Wang Z M, Mao D H, et al. Rapid, robust, and automated mapping of tidal flats in China using time series Sentinel-2 images and Google Earth Engine. Remote Sensing of Environment, 2021, 255: 112285.
51 Xiong Y M, Liao B W, Wang F M. Mangrove vegetation enhances soil carbon storage primarily through in situ inputs rather than increasing allochthonous sediments. Marine Pollution Bulletin, 2018, 131: 378–385.
52 Li H, Yin Y, Shi Y, et al. Micromorphology and contemporary sedimentation rate of tidal flats in Rudong, Jiangsu Province. Journal of Palaeogeography, 2011, 13(2): 150–160.
53 Liu Z Y, Pan S M, Liu X Y, et al. Distribution of 137Cs and 210Pb in sediments of tidal flats in north Jiangsu Province. Journal of Geographical Sciences, 2010, 20(1): 91–108.
54 Zhang Q, Wen X, Song C, et al. The measurement and study on sedimentation rate in mangove tidal flats. Tropical Oceanology, 1996, 15 (4): 57–62.
55 Li B, Liao C Z, Zhang X D, et al. *Spartina alterniflora* invasions in the Yangtze River estuary, China: An overview of current status and ecosystem effects. Ecological Engineering, 2009, 35(4): 511–520.
56 Liao C Z, Luo Y Q, Jiang L F, et al. Invasion of *Spartina alterniflora* enhanced ecosystem carbon and nitrogen stocks in the Yangtze estuary, China. Ecosystems, 2007, 10(8): 1351–1361.
57 Huang M, Ge C D, Zuo P, et al. The contribution of *Spartina* introduction on organic matter source and its effects on carbon burial in tidal flats. Journal of Nanjing University (Natural Science), 2018, 54(3): 655–664 (in Chinese).
58 Jiao N Z, Tang K, Cai H Y, et al. Increasing the microbial carbon sink in the sea by reducing chemical fertilization on the land. Nature Reviews Microbiology, 2011, 9(1): 75.
59 Jiao N Z, Zhang C L, Li C, et al.Controlling mechanisms and climate effects of microbial carbon pump in the ocean. SCIENTIA SINICA Terrae, 2013, 43(1): 1–18 (in Chinese).
60 Liu J H, Zhang F, Jiao N Z. Deciphering the mechanisms of carbon sink through a holistic view of the interactions between land and ocean. Chinese Science Bulletin,2015, 60(35): 3399–3405 (in Chinese).
61 Schuerch M, Spencer T, Temmerman S, et al. Future response of global coastal wetlands to sea-level rise. Nature, 2018, 561: 231–234.

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